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Lord Chancellor Bacon.



Engraved for the Chemical Essays from an ancient Portrait in possession of the Author.

Bacon, like Moses, led us forth at last,
The barren wilderneys he past,
Did on the very border stand
Of the blest promis'd land,
And from the mountains top of his exalted wit,
Saw it himself, and shew'd us it.
But Life did never to one man allow
Time to discover worlds, and conquer too. *Cowley*

CHEMICAL ESSAYS,

PRINCIPALLY RELATING TO

THE ARTS AND MANUFACTURES

OF

THE BRITISH DOMINIONS.

By SAMUEL PARKES, F.L.S. M.R.I. F.S.A. Ed.

Member of the Royal Asiatic Society of Great Britain and Ireland,
Fellow of the Geological and Astronomical Societies of London,
And of the Wernerian, Horticultural and Highland Societies of Scotland;
Member of the American Philosophical Society, and
Master of Arts of Yale College, Connecticut;
Member of the Imperial Natural History Society of Moscow,
The Academy of Sciences, Arts and Belles Lettres at Dijon,
And the Academy of Medicine at Marseilles;
Honorary Member of the Royal Geological Society of Cornwall,
The Antiquarian Society of Newcastle upon Tyne,
The Agricultural Societies of Philadelphia and Massachusetts, and
The Society for the Promotion of National Industry and the Arts at Lisbon;
Corresponding Member of
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Society of Paris; and the Imperial Agricultural, and Physico-Medical
Societies of Moscow, &c.

AUTHOR OF

"THE CHEMICAL CATECHISM", "THE RUDIMENTS OF CHEMISTRY",
AND OTHER WORKS.

THE THIRD EDITION,

*Revised, corrected, enlarged, and illustrated with numerous Copper Plates and
Wood Cuts of Machinery and Chemical Apparatus;*

By J. W. HODGETTS.

LONDON:

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BY J. W. HOBGETTS.

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PREFACE

TO

THE FIRST EDITION.

NOTHING can be of more importance to the people of a manufacturing country than the cultivation of a taste for philosophical and chemical inquiries. Manufactories cannot be conducted without the employment of a variety of artificial as well as natural productions, and it behoves the workmen as well as their employers, to become acquainted with the intimate nature and properties of the respective materials on which they have occasion to operate.

To enable such persons to pursue these investigations with advantage, it is requisite that they should not only possess a knowledge of the elements of chemical science, but acquire also a constant habit of observing the effects which different bodies produce upon each other, and hence learn to understand the causes of the various appearances which take place in the several operations that come under their own daily observation or particular superintendence.

To promote this desirable end, nothing would perhaps be so effectual as the dissemination of several distinct and familiar treatises on the most important manufactures of the country, and on the nature of the materials employed in them. The Essays of Bergman, Scheele, and Watson, are of this nature; and these have contributed in no small degree to the information of the public mind, and to that growing taste for chemical pursuits which is one of the characteristics of the present age.

The subjects on which these eminent Essayists have so ably written, are, however, comparatively few, and much remains to be done before an inquirer into the nature and extent of the British manufactures can obtain solid and sufficient information respecting the staple products of the country.

In the course of his business as a manufacturing chemist, the author of the following work has, for many years, been in the habit of visiting the principal manufactories of the kingdom;—of associating occasionally with the most intelligent artists in a great majority of the counties of England and Scotland;—and

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of taking notes of every thing that he saw or heard in the course of his journeys which he esteemed worth registering:—he therefore flattered himself that he possessed the means of increasing the stock of general knowledge, and that he might, without presumption, aspire to the honour of treading in the footsteps of those illustrious predecessors above mentioned.

In selecting the subjects, the author has fixed upon those which seem to have been the least examined by other chemical writers, and in all cases due attention has been paid to the improvement of the manufactures of the kingdom. With this view, he has been careful to offer, on every favourable opportunity, such hints as were likely to be most useful to the superintendents of manufactories, and such as should induce a correct chemical investigation of the nature of all those concerns in which persons of this description are usually engaged.

To attain this object, it has been found necessary to recite many chemical axioms, and to impress these upon the minds of artificers and workmen, though such may appear to the proficient in chemical science to be little more than mere truisms or trite observations. In like manner, some of the details are given with no other view than to inform those who are beginning the study of chemistry; and this may be instanced in the enumeration of the many cases in which a knowledge of specific gravity is essential, and where the author's sole aim is to induce such persons to direct their attention to this particular and important subject.

The superintendents of some manufactories may perhaps deem it superfluous to have described their processes so much in detail, because they themselves are already familiar with them; but such individuals should consider that others may profit by the perusal, and that those who are engaged in very different occupations, by reading such accounts may perceive that the improvements which are suggested for the adoption of other establishments can, with considerable efficacy and saving, be applied to their own, and thus in the end a great mass of improvement may be gained by the community at large.

It is an excellent opinion of the writer who obtained a prize from the Economical Society of Berne, for an Essay on the best means of instructing the public, that “a labourer executes easily and exactly all his works in proportion to his knowledge;—that the ignorance of the people always throws an indolence on the persons of a more elevated order;—and that the intelligence of the artist necessarily excites the emulation of the gentry and the nobility.”

Many years having now elapsed since the author began to register every thing of importance that he saw or read respecting

the British manufactures, it has become impossible for him in some instances to ascertain whether the facts were obtained from books, or from observation during his intercourse with artists and their employers; and at this distant period he is unable in some cases to discover even whether the language itself is his own, or that of others. He has, however, endeavoured to make his readers amends for this uncertainty, by referring them on every subject to the best writers within his knowledge; being ambitious that his work should be received as a book of reference to the most eminent chemical authors, so far as these have any thing applicable to the subjects on which he treats. It must always be an acceptable service to those who have chemical subjects to investigate, to be directed to original authorities, or otherwise to faithful translations, which can always be procured by many readers with greater ease than those works which are printed abroad, or even than any of the foreign Journals.

Notwithstanding the space which is occupied by such allusions and authorities, the author hopes that these volumes will be found to contain as large a proportion of *original* matter as any chemical work of the present day; and it is impossible in this advanced state of the science to write on any chemical subject, without recapitulating many facts which have been already established by a host of predecessors in the same walk of science. "Do not blame me," said Macrobius, an interesting Latin writer and eminent critic of the 4th century, "if what I have collected in reading shall frequently be expressed in the very words of the authors from whom I have taken it; for my view in this work is, not to give proofs of my eloquence, but to collect and digest, into some regularity and order, such things as I thought might be useful to be known to the public*."

In accomplishing a similar task, the author is aware that he is liable to mistakes and misconceptions, especially in his reasonings and remarks on the conduct of those manufactures in which he has never been personally engaged: he is however convinced, as Dr. Priestley has observed, "that a person who means to serve the cause of science effectually, must often hazard his own reputation so far as to risk mistakes in things of small moment†." And if it behoves one in the service of *general* science to risk that which is so valuable to every man, surely those branches of knowledge which are more intimately connected with the commerce of these dominions have the most imperious demands upon us; for "what can touch us more nearly than the improvement of our manufactures, on which the riches of our

* Præfat. ad *Saturnalia*.

† Preface to Priestley's *Observations on Air*, Edit. 1781, vol. i. p. 9.

country, and the daily bread of the greatest number of its inhabitants depend *?"

Deeply engaged in a manufactory, which demands great attention and often requires the aid of tedious experimental investigation, little time could be afforded for preparing these volumes, except in those hours which the generality of men devote to relaxation or repose.

The greater part of these Essays were, therefore, necessarily composed during the intervals of business, and often in the midst of manufactories at a great distance from home, when the author could have no access to his own library, or to books of any kind to which he might refer for authority or elucidation respecting the numerous facts which always offer themselves to the attention when treating on chemical or philosophical subjects.

From these circumstances, the Essays were at first written without any illustrations or references whatever, and the notes were appended occasionally, wherever further explanation seemed to be essential, and whenever the reading or the memory of the author furnished him with any facts of importance to which he had not already alluded. It must however be remarked, that this mode of essay-writing, though it may perhaps give a little more originality to the complexion of the composition, has entailed upon the author the very laborious task, of subsequently collecting and examining numerous authorities, in order to enable him to direct the chemist or artisan to the most authentic sources from which he could derive additional and often very valuable information.

To render these Essays more useful, the author has taken considerable pains to procure drawings of all the modern apparatus to which he has referred. These drawings were in general either sketched by himself, or by those proprietors of the several manufactories who were anxious to contribute to the work, and whose kind assistance he hereby acknowledges with gratitude.

Thus all the plates were engraved from *original* drawings, with the exception of the sal-ammoniac apparatus, which is copied from the second volume of the *Journal de Physique*. This it appeared desirable to describe, because it has not yet excited that attention which its importance and utility deserve, and few persons in this country have access to the early volumes of the foreign journal from which it was obtained.

Great care has also been taken in describing all these plates; and in order to enable the reader to construct any of the apparatus, accurate admeasurements have been given wherever there appeared to be a probability of their being useful.

* *Experiments on Bleaching*, by Francis Home, M.D. p. 147.

The pleasure which arises from the discovery of any facts not generally known ; any new elucidation of interesting truths ; or the acquisition of any scarce treatise which might afford important hints to the reader ; and the prospect of completing a work which is likely to be useful to the public, have been constant incitements to the author to persevere in the labour of research with unremitting zeal and ardour.

As a considerable mass of materials still remains with the author, he may perhaps be inclined, should it meet with the approbation of the public, to compose at some future period an additional volume of these Essays. At all events, he will continue to employ the latter years of his life in the same kind of investigations, always keeping in view the examination of every new improvement in the management of the national manufactures, well knowing that the acquisition of one new idea often gives birth to others of very superior importance.

Cardinal Farnese one day found Michael Angelo, when an old man, walking alone in the Colosseum, and expressed his surprise at finding him solitary amidst the ruins ; to which he replied, " I go yet to school that I may continue to learn." Whether the anecdote be correctly true or not, it is evident that he entertained this feeling, for there is still remaining a design by him, of an old man with a long beard in a child's go-cart and an hour-glass before him, emblematical of the last stage of life ; and on a scroll over his head, *ANCORA IMPARO* in Roman capitals, denoting that no state of bodily decay or approximation to death was incompatible with intellectual improvement. " He established it as a principle," says Mr. Duppa *, who has given us these anecdotes, " that to live in credit was enough, if life was virtuously and honourably employed for the good of others and the benefit of posterity :—and thus he laid up the most profitable treasure for his old age, and calculated upon its best resources ;—making all nature interested in the length of his days."

London,
July 8th, 1815.

* *The Life of Michael Angelo Buonarroti, with his Poetry and Letters*, by R. Duppa, Esq. 4to, London 1806.

PREFACE

TO

THE SECOND EDITION.

A CONSIDERABLE time has elapsed since the publication of the first edition of these Chemical Essays; and during this period so many new facts have been discovered, and the opinions of the most eminent chemists of every country have so entirely changed respecting some of the more interesting branches of Chemistry, that the very elements of the science have in several instances undergone a complete revolution.

On these accounts it became necessary, when preparing a new edition for the press, not only to revise every page of the work with the utmost care, but also to enlarge most of the Essays by the addition of much new matter.

It would be useless to attempt to enumerate the whole of the additions and alterations which this impression has undergone; but a few of the most important may be mentioned, for the information of those persons who may not have seen the former edition of this work.

When these Essays were written, the importance of the doctrine of definite proportions was not so generally acknowledged as it is at present; for though Higgins, Richter and Dalton had all written on the subject, it seems never to have made a general impression on the public mind, until Dr. Wollaston in the year 1814 published his Memoir on Chemical Equivalents, and with it the sliding-rule, which reduced the theory to practice, and convinced all scientific men of the importance of these helps in chemical inquiries. It was therefore thought to be of consequence, in republishing these Essays, to attach the representative number to every substance treated of therein; and this has been done in most cases.

The Notes which in the former edition were printed at the bottom of the page have been for the most part interwoven with the Text; and in order to make each Essay a complete Treatise on the subject which it professes to discuss, the various salts and other chemical compounds connected with it have been enume-

rated, and their properties and uses, where known, fully described. The Essay on the Manufacture of Tin-Plate, first printed in the Memoirs of the Literary and Philosophical Society of Manchester, is now appended to the former Essays;—a List of the various works referred to in these volumes is also given, for the purpose of showing the editions which have been made use of, and for enabling the reader to examine the extracts and verify the quotations;—and much labour has been bestowed in forming a New General Index.

The most important addition, however, is that of a very extensive Table of Chemical Equivalents. This Table has been drawn up in an alphabetical form for the sake of facility of reference; and it may be remarked that it is the only alphabetical Table yet published by any English Chemist which contains the chemical composition of each compound attached to its equivalent number. In choosing these numbers, I have adopted those which appeared to me to be derived from the best authorities, though I am well aware that a long time must elapse before any Table of this sort can be formed which will be correct in every instance.

The writers who have treated more expressly on this subject are Berzelius and Dr. Thomson; but the largest collection of modern equivalent numbers has been published by Mr. Brande in his Manual of Chemistry, and of this I have availed myself very much in the construction of this Table. Another Table has since been published by Mr. Brande, which in many respects varies very considerably from the numbers in his Manual; but as many of these appeared to me to require confirmation, I thought it most advisable to construct my Table in conformity with the numbers which I had already made use of in the body of the work.

I have much pleasure in adding, that these Essays have been twice translated into the French language, and are now selling at Paris in three volumes octavo; and that they have also been rendered into German at Weimar, at Erfurt, and elsewhere.

*Mecklenburgh Square,
June 1823.*

PREFACE

TO

THE THIRD EDITION.

EIGHTEEN months having been allowed to elapse since the last edition of Mr. Parkes's "Chemical Essays" was entirely out of print, some apology is due to the public, for delaying so long the republication of the work. One cause of this delay was an error in supposing that many more copies had remained in the publishers' hands than actually were there; so that the editor was advertised of the sale of the last copy before he had well commenced his preparations for a new edition:—another, and by far the most important, was the unforeseen difficulty of the undertaking, and length of time required for its execution. The task of publishing the twelfth edition of the "Chemical Catechism" was comparatively easy: the author had been lost to the scientific world but a few months; and although he had not actually prepared the sheets for the press, he had noted the changes and additions which he intended to make. Now, however, the case is widely different: four years have passed away since the death of Mr. Parkes, and more than six since these Essays last went to press. During this period, the rapid strides which the science of Chemistry has made, and the quick succession in which one series of improvements and discoveries has succeeded another, have only been excelled by the still more quick advances of the manufactures of Great Britain, and most particularly of those which are dependent upon Chemistry.

Thus the various new processes brought to perfection by the Calico-printer, have rendered the Essay on that subject very inadequate to give the reader an idea of the state of the art in the present day; and the difficulty of obtaining

accurate information of the manipulations required in the new processes of an art where every manufacturer has his particular and highly valued secrets, can only be appreciated by those who have laboured to get details of chemical operations for the purpose of publication. Thanks, however, to the kindness and liberality of a scientific friend, who is a considerable calico-printer near Manchester, I hope that the attempt I have made to describe the new systems will not be found destitute of information and interest to the reader.

In the Essay on Sulphuric Acid, the manufacture of which has also undergone most important changes, I had less difficulty ; as to give a history of the improvements in that art, I had little more to do than to detail the successive processes which Mr. Parkes and myself adopted in our own chemical works, where that article has always been an object engrossing a considerable portion of our attention.

All the Essays required attentive revision, and many of them great additions. I have altered Mr. Parkes's language as little as possible, preferring, where I could, to add my own matter, in lieu of changing his : and knowing that the author had intended in his next edition to compress the two volumes into one, so that the work might be obtained at one half of the expense, I have pursued that plan ; and by printing in a smaller type and closer page, I have not only given all the original Essays, with my own additions, before mentioned, but have also added one, at least as interesting and instructive as any in the book,—I mean that on the *Manufacture of Brass*,—which he wrote for the Royal Geological Society of Cornwall, and the original manuscript of which that Society obligingly lent me, to enable me to correct the imperfect copies which I possessed.

To get in so much new matter, I have omitted the list of works quoted (which are all referred to so accurately in the notes as to make a separate list of little use), as also the tables of the fusing points of metallic alloys, and some additional notes and parts of the text, which various circumstances have rendered obsolete : as for instance, every

thing concerning the abolition of the salt duties, and the laws relating thereto, which abolition was afterwards so happily achieved.

Chemists having now all agreed that the atomic weight of oxygen is eight (or at least that it is eight times that of hydrogen), and the tables of equivalent numbers being calculated on the old system of seven-and-a-half, I have had to alter not only these, but every equivalent mentioned throughout the work. To do this I have almost entirely followed *Mr. Brande's "Table of Prime Equivalent Numbers;"* in a few instances taking those of *Dr. Thomson*, as published in his "*First Principles of Chemistry.*"

It being hardly possible to retain all the plates of the two volumes, I have rejected a few which appeared to be of less utility, some of them being almost duplicates; but I have preserved fourteen, as necessary to the elucidation of the various processes described. In the *Essay on the Manufacture of Brass*, and in the additions to that on Calico-printing, I have also given wood-cuts of the furnaces and apparatus, which I hope will tend to render the descriptions of those manufactures more clear and easy to be understood. Upon the whole, I have endeavoured to render this edition such as not to be behind the recently rapid improvements in our manufactures.

Soon after the last edition of these Essays was published, the then Emperor of Russia (Alexander), in token of his approbation of the work, presented Mr. Parkes with a valuable diamond ring. Several translations, both French and German, not only of the "Essays," but of the "Chemical Catechism," and the "Rudiments of Chemistry," have also been sent him by their authors. Indeed, were any thing wanting to prove the estimation in which Mr. Parkes's books are held, the continued piracies upon them would be sufficient. During the lifetime of the author, he was frequently compelled to have recourse to the law to protect his literary property:—as late as last year it was found necessary to stop *Forsyth's "First Lines of Chemistry,"* (being almost a reprint of the "Catechism,") by an injunction of the Court of Chancery: and since that time, another free-trader, not content with unmercifully pillaging the con-

tents of the book, has actually carried his assurance so far as to adopt its very name of "Chemical Catechism."

Having prefixed a short sketch of Mr. Parkes's literary life (with an excellent engraved portrait of him) to the twelfth edition of the "Chemical Catechism," which has for some time been in the hands of the public, I will not unnecessarily swell this volume by a repetition of what has probably been already perused by most of the readers of the present volume.

JOSEPH W. HODGETTS.

47 Camden Street,
April, 1830.

DESCRIPTION OF THE PLATES.

PLATE I.

PORTRAIT OF LORD BACON.

THIS is a highly-finished likeness of Lord Chancellor Bacon, engraved by an eminent artist from an original portrait in the possession of the author. The lines underneath it were taken from a poem addressed by Abraham Cowley to the Royal Society, on its first formation, and printed in Bishop Sprat's History of the Society.

PLATE II.

Is an *improved STILL*, with its preparatory vessel as lately introduced in some of the West India Islands for the distillation of rum.

On an inspection of the ground plan of this apparatus, it will be perceived that the still, A, is of a square form : but as the bottom and the crown of this still are both curved in the same manner as a round one, the principle on which this acts is nearly the same as in a common still, except in the following particulars :

The flues under this still reverberate in the direction of the arrows, as shown in the ground plan, and are then taken up on each side of the still into the side flues, from whence the fire or flame proceeds under the preparing vessel B, round a slight partition of brick-work called a *bonnet*, then into an aperture at the bottom of the perpendicular flue, or tube, C, which passes through the centre of the liquor in the preparatory vessel, and from thence directly into the chimney D.

In common stills the heat from the fuel is not sufficiently expended under the bottom, as explained at p. 77, but quickly passes off to the sides, whereby the sides of the vessel are very soon burnt through. By this contrivance, however, the light materials which are burnt for fuel in the West Indies are nearly all consumed under the bottom of the still ; and whatever waste heat there may be, this is afterwards expended in raising the temperature of the wash contained in vessel B.

In this apparatus, b is the man-hole for clearing out the preparatory vessel, c the safety valve, and d the cock for opening or shutting the tube by which the still is filled with heated wash from the preparatory vessel B. The principal difference between a common still and this one is in the manner in which the liquor of the preparatory vessel of each is heated. That in the former is heated by the flame passing underneath it, and the latter by a heated tube which is fixed within the centre of the liquor itself, as is more particularly described at page 91.

PLATE III.

The elevation of an *Economical STILL* for general purposes.

A is a still in the usual form. B the copper head with a long pipe passing through the condensing vessel C, to the worm E, fixed within the cask or worm-tub D.

The condensing vessel C, which lies in a horizontal position, and may be supported from the ceiling or the floor, as may be most convenient, answers

two important ends in distillation which deserve attention. This preparatory vessel being filled with wash, or any other liquor intended to be distilled, materially cools the gas arising from the still, and condenses the vapour into a liquid, as it passes along the pipe e, before it reaches the worm itself; and this intermediate reduction of temperature is so considerable, that one-fourth of the water usually employed in the worm-tub is found sufficient. The second advantage arising from this peculiar construction, is, that so much caloric passes off from the tube e, into the wash contained in the intermediate vessel c, that the liquor soon becomes heated to 170° or 180° of Fahrenheit; and hence is in a very desirable state for replenishing the still. This is done merely by turning the cock d, in the pipe, which passes from the preparatory vessel to the still. Each end of the pipe passing through the intermediate vessel is secured with cement, that the vessel may at any time be taken off if required.

The orifices b and c, and the cock d, have the same uses as those in Plate II. marked with similar letters. F is the vessel placed on the ground for the reception of the product of the still. This apparatus is referred to at page 91 of this volume.

PLATE IV.

A collection of Apparatus for ascertaining the Specific Gravity of bodies.

Fig. 1 is an areometer for proving the specific gravity of fluids; it is described at page 107 of this volume.

Fig. 2. An hydrostatic balance. Its use and the different modes of employing it are explained at page 111.

Fig. 3. A jar of water in which the solids, whose specific gravities are to be ascertained, are immersed, after having been weighed in air.

Fig. 4. A cube of glass. Its use is particularly described at page 107.

Fig. 5 is the representation of a set of carat weights, such as are described at page 116, and which are extremely useful in ascertaining the specific gravity of many substances.—Tables to facilitate the use of these weights will be found at pages 117 and 119.

Fig. 6. Knight's travelling case, containing a specific gravity bottle, counterpoise weight, &c.

Fig. 7 is a drawing of Mr. Knight's gravity bottle with taper neck, for ascertaining the specific gravity of fluids where great accuracy is required.

Fig. 8 is the representation of a stopper for a specific gravity bottle, with a notch on one side to allow of the escape of the redundant fluid, as described at page 110 of the Third Essay.

Fig. 9. Mr. Nicholson's specific gravity bottle, with the conical notched stopper (fig. 8.) placed in it.

Fig. 10. The specific gravity bottle, usually employed by the author whenever he has occasion to take the specific gravity of fluids, as noted by the carat weights. The bottle itself is marked on the neck with a diamond to show how high it should be filled, and it is blown with a sort of cup at the top to receive any portion of the liquor which would otherwise be spilled in filling; but this is not well displayed in the engraving. See page 116.

PLATE V.

A Barytes Furnace, contrived for the decomposition of Derbyshire cauk, or the common sulphate of barytes.

Fig. 1. is an elevation of the furnace, as it appears when finished. Fig. 2 is as it appears before the arches are turned over it.

A is the ash pit. B the fire-place, with the fire-bars. C the bottom of the furnace on which the ground cauk mixed with the carbonaceous matter is to be exposed to the action of the fire, with continual stirring. D is the chim-

ney for carrying off the smoke, the sulphurous acid gas, and other incondensable products. E a door for emptying the ash-pit. F the furnace arch and opening to repair the furnace. G the hopper for feeding the fire. H H the doors into the furnace for the convenience of stirring the materials, and through which the sulphuret of barytes is to be withdrawn when finished. I the arch of the fire-place.—For the method of using this furnace, see page 147.

PLATE VI.

APPARATUS FOR MAKING COKE.

Fig. 1 represents the ground plan of one of the coke-ovens belonging to the Duke of Norfolk, at Sheffield.

The oven is built circular, with a wall of 18 inches in thickness. Its diameter is ten feet in the clear within side, as will be seen by a reference to the scale.

A is the platform or floor of the oven, which is elevated three feet above the ground, as will appear from an examination of the elevation fig. 2. This is contrived for the convenience of placing a wheelbarrow under the door to receive the cokes as they are drawn from the oven.

B is the opening or door-way for drawing out the cokes. It is 2 feet wide and 19 inches high to the springing of the arch. This door-way has a broad cast-iron sill built into the wall when the furnace was erected.

C the oven wall, which is 18 inches thick and 19 inches high, when measured from the floor of the oven. The diameter is then contracted, and the roof is brought in like a glass-house, to the height, when measured perpendicularly, of 3 feet 5 inches more, leaving a circular opening of two feet diameter at the top, for supplying the furnace with the coals which are to be converted into coke, and to serve as a chimney when the coals are first ignited. The latter wall is only one brick's length in thickness, and the ends of the bricks are placed towards the fire. The floor is laid with hard common bricks on the edge; common bricks are also sufficient for the first wall of 19 inches high, but it is absolutely necessary to have good fire brick for the whole of the arch or covering.

D D is a wall built with common unhewn stone, about 20 inches thick, and carried up the whole height of the oven; the void spaces in the corners to be filled with rubbish well rammed.

Fig. 2 represents a front elevation of the coke-oven, the ground plan of which has been described already.

In explaining this elevation, reference must be had to the letters engraven upon the plate.

C is intended to show the line of the oven floor.

D the height of the oven wall where the brick-work begins to contract.

E the door-way for taking out the cokes when sufficiently burnt.

G G shows a section of the arched roof of the oven; but this is not seen in the front elevation, as the front wall and the backing of earth hide it.

The coke-ovens are used thus:—Small coal is thrown in at the opening fig. 2, sufficient to cover the bottom of the oven 19 inches thick to the springing of the arch, which is about two tons; they are then levelled, and the door E built up with loose bricks. The heat of the oven sets the coal on fire, which is accelerated by the atmospheric air rushing in through the joints of the loose bricks in the door-way. In the space of two or three hours the door-way is plastered up with a mixture of wet soil and sand, except the top row of bricks, which is left unplastered all night. This is generally plastered up close in about 24 hours after the coals are first put in, the chimney remaining open till the flame is gone, which is generally quite off in 12 hours more. A few loose stones are then laid over the chimney, and those covered up with sand or earth. After this is done, the cokes remain in the ovens 12 hours

longer, and are then drawn out into wheelbarrows and carted away by the customers. The whole takes up 48 hours; and as soon as the cokes are raked out, the ovens are re-filled with small-coal for another burning.

Fig. 3 represents a new mode of burning cokes in the open air by means of a large chimney round which the coals are piled. The method of managing this process is fully described at page 183.

PLATE VII.

This engraving is the representation of an Elaboratory constructed for the express purpose of preparing the Crystallized Citric Acid.

A A A are pipes of lemon-juice, supposed to be in the state in which the article is usually imported.

B is a large wooden vat for saturating the acid with calcareous earth, and capable of holding two or three hundred gallons.

C C. These are copper pumps suitable for pumping the juice from the casks into the saturating vat.

D is a large wooden tub for decomposing the citrate of lime by means of sulphuric acid, when it is removed from the vat B.

E is a leaden boiler of an oblong square for concentrating the acid liquor from the vessel D.

F F are two round boilers of lead of different sizes, and suspended in water baths. These are employed for the further concentration of the liquid citric acid. In the smaller of these the acid is brought to that syrupy state which is most suitable for it to be laid out to crystallize.

G G G G. These are pans of earthenware or glass into which the concentrated acid is poured to cool and crystallize.

H is a leaden syphon to be employed in running off the waste liquor from the vat B when the acid has been abstracted from it by the chalk.

K is a shelf for holding bottles of chemical tests, trial glasses, or any other small articles required in the manufactory.

L a moveable strainer for clearing the mother liquors, and other purposes of the manufactory.

PLATE VIII.

Apparatus for making Charcoal and distilling Pyroligneous Acid.

Fig. 1 represents a section of a charcoal cylinder when fixed within the furnace. It is cut lengthwise through the middle, to show the internal work.

Fig. 2 is a contrary section of the same cylinder, the end or front wall being in this case taken away to show how the fire plays round it before it passes off by the chimney.

Fig. 3 is an elevation of the building which incloses a cylinder when properly fixed, together with the fire-place, the tubes to carry off the acid and gas, the wine casks to receive pyroligneous acid, &c. complete.

Fig. 4. The outer shutter, to contain the stopping or luting which makes the cylinder air-tight during the operation of distilling the acid and charring the wood.

Fig. 5. The inner shutter, or stopper to prevent the stopping from getting among the charcoal.

PLATE IX.

The elevation and plan of a Reverberatory Furnace on an improved construction.—The separate parts may be thus described:

A is a door by which the oven is charged, the size of which may with convenience be 9 inches by 12 inches.

B B B are three strong bands which go on each side of the furnace. These are fastened together by cross bars of iron which go through the brick-work of the

furnace, and over the top of it, and are bound tight against the walls by screws and bars, as shown in the engraving.

C the ash-pit.

D an iron damper which runs within a groove in the brick-work of the chimney, to regulate the draught or entirely stop it at pleasure.

E the passage from the oven to the chimney.

F is a faint line on the wall of the elevation to show how the arch of the roof lessens in height as it approaches the chimney. This is designed for throwing the flame more down upon the materials before it enters the chimney, and has the effect of rendering the temperature of the oven the same in all its parts.

G is the floor of the oven, 4 feet long and 2 feet $2\frac{1}{2}$ inches wide.

H is the fire-place with an iron hopper such as is described at page 81.

I are the fire-bars, with their ends projecting, as shown in the elevation, for the convenience of drawing them easily whenever it may be necessary either to cool the furnace or take out the clinkers. When the bars of a furnace are fixed in this manner, they may be readily taken out with a pair of tongs, and then the whole of the contents of the fire-place will fall into the ash-pit.

K is the bridge which divides the floor of the oven from the fire-place. This should be 14 inches thick and 9 inches high, and built with the best fire-bricks. It is important to build it with very *close* joints and with fire-clay instead of mortar, as the bridge usually wants repair before any other part of the furnace.

As this drawing is an exact representation of a very useful reverberatory furnace which was erected at my own manufactory, it may perhaps be acceptable if I annex the measures of the principal parts, for the guidance of those persons who may be desirous of constructing a similar furnace.

The whole length measured on the outside is 8 feet, the width 4 feet 2 inches, and the height from the floor to the top of the covering 4 feet 6 inches. The fire-place 17 inches by 20 inches, the ash-pit 10 inches wide, and 2 feet 4 inches from the ground to the underside of the fire-bars. The height of the oven from the floor of it to the underside of the arch is 17 inches at the bridge, and 12 inches if measured at the chimney. The measures of the oven floor, the door and the bridge, have been noticed before.

PLATE X.

Is the representation of Crown Glass in its various states, from the time it is taken out of the furnace until it becomes a perfect circular sheet of window-glass.—The whole is fully explained in the Essay.

PLATE XI.

Is descriptive of an Apparatus for Bleaching Cotton Goods.

Fig. 1 is a section of the bucking apparatus, which may be thus described :

A is the boiler for heating the alkaline lye.

B represents a very large wooden vessel in which the calicoes are placed.

C the cock and pipe, by means of which the hot lye is conveyed upon the goods.

D is a square box designed for spreading the lye over the calicoes within the vessel B.

E a pump for raising the liquor again out of the vessel B, whence it is conveyed by the spout I back into the boiler A.

F is the furnace for heating the lye.

G represents the false bottom of the calico vessel, full of holes for the passage of the lye when it has run through the goods under operation.

H is a round wooden staff which completely fits a hole at the bottom of the bucking vessel. It is called a duck, and is intended to be pulled up whenever it is designed to run off the spent alkaline liquor.

I is the spout for conveying the liquor back to the boiler as above mentioned. In some houses the boiler is fixed below the bucking vessel, and the pump is placed within the boiler as described in page 391.

Fig. 2 is the representation of a common whale-boiler.

A is a metallic boiler to be fixed in brick-work, similar to that in fig. 1.

B B is the top part of wood, called a crib, with the bottom full of holes. In this the calicoes are placed one above another, often amounting to many hundred pieces at one operation.

C is the pipe through which the lyes boil up, and d d is the umbrella suspended over the pipe for the purpose of spreading the lyes more effectually as they fall down again upon the goods.

This apparatus for bleaching possesses several advantages. The perforated wooden vessel preserves the calicoes from being injured by coming in contact with the boiler, while the pressure occasioned by so great a weight of goods frequently increases the temperature of the lye by some degrees higher than it would acquire in an *open* vessel, and this additional heat has a powerful effect in bleaching. By this contrivance there is no necessity for pumping; for, so long as the lye in the vessel A actually boils, a constant stream will flow through the pipe C upon the goods in B, and thus a perpetual circulation may be kept up till the goods have attained the desired whiteness.

PLATE XII.

This plate contains two representations of Mr. Lucas's Furnace for converting Cast-iron Cutlery to good Steel Cutlery.

Fig. 1 is a front view of the furnace complete.

B B are cast-iron bearers for supporting the grate bars.

D foundation wall below the floor of the work-shop for supporting the interior of the furnace.

E E the two fire-places for heating the furnace. 2 is the dome or arch of the furnace. 3 3 the internal side of the front wall, in which is an aperture 4, by which the workman enters to place the iron cylinders holding the goods. This being done, the aperture is walled up as shown in the engraving, except two holes left in the bottom of the wall marked 5 5.

H is the chimney for conveying away the smoke of the fire-places.

Fig. 2 is a perpendicular section of the same furnace, presenting a side view of its internal parts, and showing how the iron cylinders which hold the cast-iron cutlery are exposed to the action of the fire. The several parts may be thus described:

A shows the length and depth of the ash-pit.

B is the representation of one of the grate bars at full length.

E the fire-place.

F the opening for supplying the fire with fuel.

G a dotted line to show the height of the shop floor.

I I the outside wall of the furnace.

KK the iron cylinders as they stand 3 in height in the furnace, the lowermost of which are raised a few inches from the platform by being placed on pieces of brick, the intention of which is to afford the fire access to every part of them. In describing the other parts of this furnace, it may be said that 2 is the dome of the furnace; 4 is the temporary wall which is built up to close the aperture spoken of in describing the elevation fig. 1, and which in that drawing is marked 4; 5 is one of the holes left at the bottom of the said wall; 7 is another temporary wall of loose bricks; 6 is the space between the two walls; 8 the chimney; 9 an opening in the outer wall, the same width as 4; 10 a cast-iron bearer reaching across the opening to support the front of the chimney.

PLATE XIII.

Mr. Parkinson's Machine for Printing three distinct Colours at once on Calico, referred to at page 555.

A a screw to give the proper pressure to the main roller. There is a similar one at the other end of the machine.

B a screw to give the necessary pressure to the copper roller C.

C a copper roller, with one of the patterns engraved on it. This receives the colour from a small box at the top, which could not be shown in the engraving.

D is the main roller of iron, round which the calico passes in order to receive the printed impression from the three smaller rollers C, G and G.

E a wooden roller to guide the blanket, against which the white calico lies. This blanket could not be distinctly shown in the engraving.

FF two blankets to receive the colour from the two colour-boxes H H. On these blankets the respective colours become by the rotary motion uniformly spread by the time they arrive at the rollers G G, on which these are to be deposited.

G G two wooden rollers with patterns cut upon them. Each of these, as before mentioned, receives the colour from the blanket F, which moves underneath, and immediately imparts it, in the desired pattern, to the white calico which revolves by an equable motion round the large iron roller D.

H H two wooden troughs containing the prepared colour. These the workmen call *colour-boxes*.

I I two large wooden rollers, designed to guide and stretch the colour-blankets.

K K two wooden rollers revolving within the colour-boxes H H. These are contrived for feeding the blankets with colour.

L eight rollers of wood, four of which belong to each colour-blanket. These rollers are merely designed for stretching and guiding the blankets.

M the large roll of white calico in a prepared state fit for printing.

N the calico in a printed state, after it has received the impression of the three patterns, in three distinct colours, from the rollers C, G and G.

Twenty pieces of white calico, containing twenty-eight yards each, and skewered together by their ends, are generally printed by this machine at one operation, it being so contrived that they pass over the three different rollers in one continued uninterrupted line until the whole is printed. This machine is capable of printing about seven yards of calico every minute.

PLATE XIV.

APPARATUS IN CALICO-PRINTING.

Fig. 10 is the representation of a steam apparatus for drying calicoes. A A A A A A are six distinct hollow copper rollers containing steam. Round these the damp calico is wound in succession, by a power acquired from a steam-engine, and by the heat of these cylinders the cloth is completely dried. B B B are three fans or vanes, also moved by the steam-engine, and calculated for promoting a perpetual circulation of air to expedite the drying process. C is the heap of damp calico intended to be dried. D the calico as it is wound off the cylinders in a dried state.

Fig. 11 is an apparatus for printing pencil-blue on calicoes, with greater certainty than has ever before been attained. It is fully described at page 545.



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CHEMICAL ESSAYS.

ESSAY I.

ON THE IMPORTANCE AND UTILITY OF CHEMISTRY TO THE ARTS AND MANUFACTURES OF THE BRITISH DOMINIONS.

THE discovery of the loadstone and its important application in the construction of the mariner's compass were the means of producing a general intercourse among nations. The subsequent invention of printing occasioned a rapid progress in that civilization which had thus been much promoted by the increase of commerce, and by the consequent interchange and general dissemination of the useful arts.

These arts consisted, however, of mere traditional processes which had been communicated, like the secrets of the alchemists, from generation to generation, without science, or any theory on which the true knowledge of them might be founded; nor was it until Lord Bacon had shown the necessity of interrogating nature by experiment, that any rational system of philosophical inquiry was pursued or promulgated.

This illustrious philosopher was indeed the first writer who seems to have had a just view of the character and labours of the Alchemist. By showing how little can be done by reasoning on the works of Nature, until a mass of facts is obtained by experiment, he benefited the world more than a host of his predecessors had done by their conjectures and conceits.

From this period, however, general science made rapid advances in improvement; and if one branch be more indebted to this great but unfortunate philosopher than another, it unquestionably is that of Chemistry, which has eminently availed herself of his grand precept, and continued her unremitting researches until nothing will now satisfy the curious inquirer, but plain facts and lucid deductions from experiment or analogy.

In this state of the public mind, what can be expected throughout Europe but a rapid succession of improvements in the arts

and which of them may be worked to advantage. Thus he will operate on sure grounds, and be prevented from engaging in expensive and unprofitable undertakings.

Chemistry will teach him also how to improve the *cultivated* parts of his estate; and by transporting and transposing the different soils, he will soon learn some method by which each of his fields may be rendered more productive.

The analysis of the soils will be followed by that of the waters which rise upon, or flow through them; by which means he will discover those proper for irrigation; a practice the value of which is sufficiently known to every good agriculturist, and well described in an excellent essay by the Rev. T. Wright, published by Scatcherd and Co., 1789, which is deserving the attention of every practical farmer.

Should he himself occupy the farm, and become the cultivator of his own estate; he must of necessity be a chemist, before he can make the most of his land, or put it into a high state of cultivation, at the smallest possible expense. It will be his concern not only to analyse the soils on the different parts of his farm, but the peat, the marle, the lime, and the other manures must be subjected to experiment, before he can avail himself of the advantages which they possess, or before he can be certain of producing any particular effect by their means. In the second volume of *The Memoirs of the Imperial Academy of Sciences at Brussels*, quarto, 1780, is an ingenious Chemical Essay, by Mons. De Beunie, on Soils, and more particularly on the Cultivation of Heaths.

Besides, a knowledge of the first principles of chemistry will teach him when to use lime *hot* from the kiln, and when *slacked*; how to promote the putrefactive process in his composts, and at what period to check it, so as to prevent the fertilizing particles becoming effete, and of little value. The Earl of Dundonald has remarked, that "vegetable putrefaction can take place only when attended with air, moisture, and a due degree of heat. Water is then decomposed—vital air absorbed—heat disengaged—and new combinations formed."—*Treatise on Agriculture*, quarto, London, 1803, page 28. It will also teach him the difference in the properties of marle, lime, peat, wood-ashes, alkaline salt, soap waste, sea water, &c., and, consequently, which to prefer in all varieties of soil. Dr. Home in the year 1758 published a valuable treatise on this subject. Indeed he was the first person that we know of, who made direct experiments on the fertilizing properties of saline matters. A knowledge of the chemical properties of bodies will thus give a new character to the agriculturist, and render his employment rational and respectable. Lavoisier cultivated 240 acres of land in La Vendée on chemi-

cal principles, in order to set a good example to the farmers; and his mode of culture was attended with so much success, that he obtained a third more of crop than was procured by the usual method, and in nine years his annual produce was doubled.—Lalande's *Life of Lavoisier*.

Are you a practitioner of MEDICINE, and have you acquired great and deserved reputation in your profession,—if you are not a chemist, you must recollect many painful disappointments, and must have witnessed very unexpected results from the effects of medicine, when you have administered two or more powerful remedies in conjunction. A slight knowledge of chemistry would have informed you that many of the formulæ in the Pharmacopœia, which are salutary and efficacious, are rendered totally otherwise, not to say often destructive, if given with certain other medicines. Many instances of these chemical changes might be adduced, but one will suffice. Mercury and chlorine have both been administered by medical men; and *separately*, either of them may be taken in small quantities, without any injury to the animal economy: but if these substances should be given *in conjunction*, the most dreadful consequences might ensue, as the product of this mixture (*corrosive sublimate*) is a most active and powerful poison. Boerhaave more than a century ago wrote a treatise to show the importance of chemistry to the medical profession, under the title *De cognoscendis et curandis Morbis*. The first person who attempted to improve pharmacy by the introduction of the metallic oxides was Paracelsus in the sixteenth century. Philip of Sides had indeed in the fifth, introduced what he called the tincture of Indian iron, but there is no proof that this ever came into general use.

If the profession of medicine be your son's choice, charge him; when he shall walk the hospitals, to pay particular attention to the Lectures on Chemistry, and to make himself master of the component parts of the different salts, and of the chemical affinities which subsist between them and the various articles with which they are generally employed; for so ignorant were the professors of medicine of the nature of the salts, that no longer ago than the year 1765 there was a public dispute between the celebrated Margraff and Mons. De Machy respecting the base of the *super tartrate of potash*, whether or no it was an alkali. This will inspire him with professional confidence; and he will generally be as sure of producing any particular chemical effect upon his patient as he would if he were operating in his own laboratory. Besides, the human body is itself somewhat analogous to a laboratory, in which by the varied functions of secretion, absorption, &c., composition and decomposition are perpe-

tually going on: how, therefore, can a medical man ever expect to understand animal physiology, so necessary in the practice of physic, if he be unacquainted with the effects which certain causes chemically produce? Every inspiration we take, and every pulse that vibrates within us, effects a *chemical* change upon the animal fluids, the nature of which it requires the acuteness of a profound chemist to perceive and understand. The use of the blood in respiration was first demonstrated by Priestley, whose interesting paper on that subject was read to the Royal Society the 25th January 1776. Mr. Professor Brande has written an excellent and very original paper on the colouring matter of the blood, in the *Phil. Trans.* for 1812, page 90. Neither can a physician comprehend the nature of the animal, vegetable, or mineral poisons without the aid of chemistry. Many thousand lives have been lost by poison, which might have been saved had the physician been in possession of the knowledge which he may now acquire by a cultivation of chemical science. And though the operation of many of the poisons upon the system be in these days well understood, nothing but a knowledge of chemistry can enable the practitioner to administer such medicines as will counteract their baneful effects.—A circumstance which came within my own knowledge, will sufficiently exemplify this position.

In the year 1805, an apothecary in one of the northern counties having drunk some bottled porter was seized with symptoms which convinced him that he was poisoned; but not knowing what noxious matter he had taken, and being incapable of analysing the remainder, no antidote could be applied, and he gave himself up as lost. A physician had been called in: but neither he nor the patient, nor his partner, could get any information by examining the remaining contents of the fatal bottle; though, I understand, they are all intelligent men, and in great repute in their profession. In this dilemma what could be done? It was recollected, however, that a neighbouring gentleman had the reputation of being a good chemist. To him the physician and the partner of the patient hastened, to get the dregs analysed, and to learn what ought to be administered. Fortunately, this gentleman had just received Götting's Book of Tests, which I had procured for his brother, and which had been sent to him but a very short time before. By this book he was enabled to ascertain that the poison was oxide of antimony: and when the patient was informed of it, he recollected that antimonial wine had been kept in a similar bottle some years before; and supposed that the porter must have been bottled without the dregs being properly washed out. This circumstance led to the proper antidote, which was administered immediately; and the life of

the unfortunate man was preserved: but, in consequence of the loss of time, the poison had so far taken possession of the system as to deprive him of the use of a limb.

If we look to the national MANUFACTURES, there is scarcely one of any consequence that does not depend upon chemistry, for its establishment, its improvement, or for its successful and beneficial practice;—though, in order to see the real connexion which subsists between chemistry and the arts, it will be useful to take a short view of the principal trades which are carried on in these kingdoms.

One of the staple manufactures of the country is that of IRON: and it will be found that, from the smelting of the ore to its conversion into steel, every operation is the effect of chemical affinities. In the first place, it requires no small share of chemical knowledge, to be able to appreciate the *value* of the different ores, and to erect such furnaces for their reduction as may be contrived in the best possible manner for facilitating their fusion, and for producing good pig-iron. The subsequent processes, to convert the crude metal into malleable iron, are also entirely chemical, and will be conducted to the best advantage only by those who have acquired a scientific knowledge of the changes which take place in these operations.—The making of CAST STEEL, which has been kept so profound a secret, is now found to be a simple chemical process, and consists merely in imparting to the metal a portion of carbon, by means of fusing it in crucibles with carbonate of lime, or by cementation with charcoal powder, in a peculiar kind of furnace constructed for that particular purpose.

Some of the steel-works in the North have these furnaces extremely large, and I have been told that the increase in weight which the iron acquires from the carbon to convert it into steel is amply sufficient to defray all the expenses of fuel and attendance. The German steel is made directly from cast iron, and this is effected merely by forging the crude metal only to a certain point.

The ancients, it is believed, had some peculiar method of making steel. This suspicion is grounded on the hardness of some of their statues, as well as on the nature of the Egyptian obelisks, which are carved with a variety of figures, and yet are made out of porphyry that resists the tools of modern times. Dr. Lister (in a paper read before the Royal Society) complains that this valuable secret is now lost. According to Aristotle and Pliny, the ancient steel was made by keeping forged iron for a certain time in melted cast iron.

The manufacturers of *chemical utensils*, and other articles too various to be enumerated, in cast iron (called IRON-FOUNDERS) will also acquire some valuable information by the study of che-

mistry; as it will teach them how to mix the different kinds of metals; how to apportion the carbonaceous and calcareous matter; and how to reduce the *old* metal, which they often receive in exchange; many hundred tons of which are annually sent away as ballast for ships, for want of that knowledge which would enable them to convert it into good saleable iron. Indeed, before the smelting of ores was properly understood, great part of the iron was not extracted in the first instance, but was thrown by with the dross; and I have understood that there are heaps containing many thousand tons of such scoria now lying in the forest of Dean, in the county of Gloucester, which the proprietor finds it his interest to work over again; as they are not only rich in metal, but yield better iron than could be obtained from the original ore.

In like manner the founder of printers' types has derived great advantage from a knowledge of the methods of reducing metallic oxides. In this trade fires are kept under the pots the whole day, to preserve the metal constantly in a melted state; the consequence of which is, that the metal at the surface perpetually oxidizes and must be frequently removed. Formerly these skimmings were called *dross*, and were thrown away as of no value. At length an individual made an experiment upon them, and at this day every manufacturer knows how to convert this refuse into good useful type-metal: so that a large manufacturer will now annually recover from three to four tons of metallic alloy, worth at least 100*l.* per ton, from these skimmings.

When we consider the WOOLLEN, the COTTON, and the CALICO manufactures, how great is the importance of each of these trades to the British dominions! To preserve these sources of national wealth, the utmost attention must be paid to the beauty, the variety, and the durability of their several colours. Now of all the arts, none are more dependent upon chemistry than those of DYEING and CALICO-PRINTING. The first account of dyeing that we have in the English language was written by Sir William Petty, at the desire of the Royal Society, entitled "*An Apparatus to the History of the common Practices of Dyeing.*" A copy of this piece may be seen in the Bishop of Rochester's *History of the Royal Society*, quarto, London, 1667, page 284. Every process is chemical; and not a colour can be imparted, but in consequence of the affinity which subsists between the cloth and the dye, or the dye and the mordant which is employed as a bond of union between them. It is then surely evident how valuable a chemical education must be to that youth who is designed for either of these trades, and how necessary is that portion of knowledge which shall enable him in a scientific manner to analyse his different materials, and to determine the kind and

the quantity necessary for each process. After all, his colours will be liable to vary, if he do not take into the account, and calculate upon, the changes which take place in them by the absorption of oxygen; on which subject some valuable information may be found in Fourcroy's *System of Chemistry*, vol. viii. pages 70—78.—Berthollet's *Elements of the Art of Dyeing*, vol. i. pages 45—65, and in a memoir "*On the Coloration of Vegetable Matters by Vital Air*," in the 5th tom. of *Annales de Chimie*, pages 80—91. A knowledge of this, and of the different degrees of oxidizement which the several dyes undergo, requires no small share of chemical skill: and yet this skill is absolutely necessary, to enable either the dyer or the calico-printer to produce in all cases permanent colours of the shade which he intends. Moreover, these artists must be indebted to chemistry for any valuable knowledge which they may acquire of the *nature* of the articles they use in their several processes; not to say that they are wholly dependent upon this science for the artificial production of their most valuable mordants, and for some of their most beautiful and brilliant colours. An instance or two will render this evident.

Formerly a calico-printer required many weeks to produce a printed cotton with some colours, such as an olive ground and yellow figures; a scarlet pattern on a black ground; or a brown ground with orange figures: but, by means of chemical preparations, the whole of this work may now be done in a few days; patterns more delicate than ever, may be produced; and all with a degree of certainty of which former manufacturers had no idea, the system being now entirely altered. According to the former practice, the mordant was first applied to those parts of the cloth that were intended to be olive, brown, or black; it was then necessary for the piece to remain some time before it could be dyed, and afterwards to be exposed in a bleaching-ground a sufficient time to clear those places from the colouring matter of the dye which had not been acted upon by the mordant: a different mordant was then applied by the pencil: and it was necessary to pass the whole piece through the dyeing copper a second time, in order to give the desired colour to those particular parts, and finish the pattern.

Now, all these effects are produced by dyeing the cloth a self colour in the first instance, and afterwards merely printing the pattern with a chemical preparation, which discharges a part of the original dye, and leaves a new colour in its stead. Thus a brown may be changed in an instant to an orange; a dark olive to a yellow; or a black to a bright scarlet. In consequence of similar improvements, rich chintz patterns, which formerly re-

quired two years or more to be completed, are now commonly finished in a few weeks.

Again,—it was not known how to dye wool of a perfect scarlet till the preparation of the nitrate of tin was discovered by a foreigner. Cornelius Drebbelius of Alcmarr in the United Provinces, a man in great esteem with King Henry VIII., made this important discovery; and having left in writing a particular method of making this mordant and of its application in dyeing, Kuster, or Kustelaer, his son-in-law, brought it to England, and about the middle of the 16th century settled as a dyer, at Bow, near London, where he acquired considerable emolument. See Dallow's *Boerhaave*, 4to, 1735, vol. i. page 58.

The art of BLEACHING, which is so intimately connected with calico-printing and dyeing, has also received such improvements from the science of chemistry, that no man is now capable of conducting it to the best advantage, without a knowledge of the real principles on which the present practice is established. The person who has written the most at large on this subject is Charmes; his book was translated by Mr. Nicholson into the English language, and was published by Robinsons, 1799, 8vo, with many plates of apparatus, &c.

The manufactures of EARTHENWARE and PORCELAIN, which were so much improved and extended by the ingenious and indefatigable Wedgwood, and which are become by his means a source of national wealth, and give employment to thousands of the community, are in like manner dependent upon chemistry for the successful management of all their branches, from the mixture of the materials which form the body of the ware, to the production of those brilliant colours which give a value to the manufactures by their permanency and beauty. Dibutades, a potter of Sicyon, first formed likenesses in clay at Corinth, but was indebted to his daughter for the invention. The girl, being in love with a young man who was soon going from her into some remote country, traced out the lines of his face from his shadow on the wall by candle-light. Her father filling up the lines with clay formed a bust, and hardened it in the fire with the rest of his earthenware.—*Athenag. Apolog.* p. 19. edit. H. Steph. 1557. Porcelain was made by the Chinese and Japanese some hundred years before it was manufactured in Europe. No china was made in this quarter of the world before the beginning of the eighteenth century.

Mr. Wedgwood was so sensible of the importance of chemistry to these arts, that he not only applied to the study of the science himself, but, upon the death of the celebrated Dr. Lewis (author of the *Commercium Philosophico-Technicum*), he engaged his

assistant, a Mr. Chisolme, to experimentalize with him, and to devote his whole attention to the improvement of the manufacture by the application of his chemical knowledge, of which perhaps few men in the kingdom at that time had a larger share. A faint idea of the advantages which he derived from these sources may be conceived from the following circumstance:—Dr. Bancroft, in his “Philosophy of Permanent Colours,” when treating on iron, says, “I remember having been told by Mr. Wedgwood, that nearly all the fine diversified colours applied to his pottery were produced only by the oxides of this single metal.” This one fact is sufficient to show with what assiduous application he must have studied chemical science, and how insufficient every attempt to bring his manufacture to the perfection which it has now attained, would have been, without this attention. An account of the respective colours which the different metals produce on porcelain may be seen in the xiiith vol. of the *Phil. Mag.*, page 342: and vol. xiv. page 17, &c.

The sister art, that of making GLASS, is also entirely chemical, consisting in the fusion of siliceous earth with alkali and the oxides of lead. In the reign of the Emperor Nero, glass was so scarce at Rome that two small cups made of it sold for the immense sum of six thousand sesterces.—*Pliny*, l. xxxvi. c. 26. In this trade, as well as in many others, the chemical manufacturer, and the man of enlightened experience, will have many advantages. He will not only know how to analyse his alkalies and to ascertain their exact value before he purchases them, but he will be enabled on chemical principles to ascertain the exact quantity necessary for any fixed portion of silica, which, to those who are ignorant of our science, must always be a matter of uncertainty, and must repeatedly subject them to losses and disappointment. Since it has been understood how to apply the oxides of metals so as to produce various permanent colours in vitrifiable substances, some ingenious workers in glass have been enabled to produce several curious imitations of many of the gems and precious stones. The works of Neri and Blancourt contain the best directions we have at present in print on this subject.

The TANNING OF HIDES was without doubt a process of remote antiquity; for the contemporaries of Moses not only tanned leather, but knew also how to colour it. *Skins dyed red* are often mentioned in the sacred books. *Pliny* attributes the invention of leather to Tychius of Bœotia. It was formerly carried on by persons who merely followed a routine of operations, to which they had been accustomed, without knowing the real cause of any of the changes produced. It has now, however, been well ascertained that the whole art consists in impregnating the animal

matter with that peculiar principle taken from the vegetable kingdom, called *tan* (or *tannin*), the effect of which may be explained entirely on chemical principles. It is also now known that many substances, besides oak bark, contain tan; and to chemistry we are indebted for the means of discovering with accuracy the *quantity* of tan which the several astringent vegetables contain. Besides, this principle having been formed *artificially* by a modern chemist, it is not improbable, that, whenever these manufacturers pay a proper attention to the science we recommend, they may be able to direct us how to prepare for them, in our laboratories, the article in question, so as entirely to supersede the use of oak bark. This would be an event of great national importance, as the demand at present is so great, that it is not only imported from the continent, but trees, it is well known, have been actually cut down on purpose for the bark. Should the chemical tanner not be fortunate enough to make a discovery of the kind just mentioned, he will at least be able to analyse the substances now in use, and to appreciate their *relative* value; a matter of no small moment to a man who operates upon a large scale. And it is not impossible but he might discover some way of employing to advantage the several refuse articles which a tan-yard produces, and which are now put aside as of no value. The old tan which is thrown out of the tan-pits was considered to be of no use until the arrival of King William III. in this island. He had observed that it was employed in Holland for raising orange-trees, and he introduced the use of it here for the same purpose. It has since been brought into general use, and is now in great estimation with most of our gardeners; the great and continued heat which it produces renders it proper for every species of forcing. Chemistry will enable him also to combine the tanning principle with the skins, so as to form leather the most impervious to moisture; and to give the hides the greatest increase of weight in the least possible time:—and these are the main secrets on which the profit of the trade chiefly depends.

The property which tan has of combining with gelatine, and therewith forming an insoluble precipitate, may be applied to the important purpose of purifying rancid fish oil. I once knew a gentleman who fitted up a very complete apparatus with this intention; and by agitating the oil with the tannin and water in a large vessel, to which he gave a rotary motion, the tannin became intimately combined with the gelatinous impurities, and then completely subsided. By this means the oil, which was fit only for burning in the street lamps, was rendered free from smell, nearly equal to the best spermaceti oil, and fit for burning in the closest chambers.

Some of the manufacturers of MOROCCO LEATHER, an article nearly new as a production of this country, have the utmost reason to regret the want of chemical knowledge.—Until within these few years, the consumers of morocco depended entirely on a foreign supply, many fruitless attempts having been made to prepare the article in this country. Later trials, with various chemical mordants, have, however, so far succeeded, that several manufactories have been established in the metropolis, within the last twenty years, where the most beautiful moroccos are now prepared at prices which have superseded the necessity of all foreign importation. The reds and yellows are the principal colours for morocco leather, and in these our manufacturers were very deficient, till a Mr. Philipppo, a native of Turkey, introduced the eastern mode of management, for which he received the gold medal and 100*l.* from the Society for the Promotion of Arts, Manufactures and Commerce. Since then we prepare this leather in a manner much superior to any that can be brought from abroad, and large quantities of it have been exported to foreign markets. Notwithstanding this, some colours are still produced by our manufacturers in a tedious and expensive way:—a series of well-conducted and appropriate chemical experiments would no doubt direct them to prepare the same colours, with greater certainty, and by a more economical process.

The manufacture of SOAP, is first noticed by one of the Hebrew writers: “Though thou wash thee with nitre and take much soap, yet thine iniquity is marked before me.”—*Jeremiah* ii. 22. *Ætius*, who flourished about the end of the 4th century, and was the first Christian medical writer, speaks of a black soap; and *Paulus Ægineta*, a Greek physician, who lived in the early part of the 7th century, says he made an extemporaneous soap from oil and the burned dregs of wine. This art is one of such considerable importance, that in the year 1795 the Committee of Public Safety in France, engaged those celebrated chemists Mess. Darcet, Lelievre, and Pelletier, to investigate the nature of the art, and to endeavour to ascertain how the various processes might be improved by chemical science. Their report is printed at large in the *Annales de Chimie*, tom. xix. pages 253—354. It materially aids the revenue of the country, but has in general been conducted, like many of the foregoing, without any regard to system: and yet, perhaps, there is no manufacture which can be benefited in such various ways by chemistry as this. To those who are designed for this trade I have no hesitation in recommending the study of the science as a matter of the first importance. Many thousands per annum, now lost to the community, would be saved, if the trade were universally carried on upon scientific principles. Make a soap-boiler a good chemist,

and you teach him how to analyse barilla, kelp, potass, &c., so as to ascertain the proportion of alkali in each,—the only sure guide to purchasing with advantage and profit, which with the common manufacturer is mere chance. When these articles are at an exorbitant price, he will have recourse to various residuums, which he will decompose by *chemical* means, and make use of as substitutes. In choosing his tallows, he will learn how to avoid those which contain a large portion of sebacic acid, which require much *more* barilla than good tallow, and yet produce *less* soap. He will know how to oxidize the common oils and oil dregs, so as to give them consistence, and render them good substitutes for tallow,—and how to apportion his lime so as to make his alkali perfectly caustic, without using an unnecessary quantity of that article. He will likewise be aware of the advantage to be derived from oxidizing the soap while boiling. A knowledge of chemical affinities will teach him how, at a cheap rate, to make as good and as firm soap with *potash*, as with the mineral alkali; and how to take up the heterogeneous salts, so as to give the alkali full opportunity of forming a chemical combination with the tallows and other oleaginous matter upon which he may be operating. And lastly, he will know how to make use of the *waste* lyes so as to decompose the salts which they contain, and convert them to good and serviceable alkali, fit for future operations. Some of the manufacturers of soap avail themselves of none of these advantages.

An example of the benefit which may arise to the arts from a chemical examination of the nature of bodies, may be seen in the employment of the chemical residuums just mentioned, and which were formerly thrown away as useless. The old makers of Glauber's salt regularly threw away the muriatic acid which resulted from the process; and the sulphate of potash, which remains after the distillation of nitrous acid, was formerly thrown into the Thames. Now, these articles are employed in various manufactories, and turn to a good account. I have indeed been told that Mr. Steer, a very large aqua fortis maker at Bir-stall, near Leeds, was for many years accustomed to lay his glass retorts in a shallow rivulet which ran through his fields, where, in a few weeks, the indurated salt was dissolved, and gradually washed away in the water. By this management he avoided the necessity of breaking the retorts: but from the extent of his business, I am persuaded that the salt thus lost for a number of years would have brought him some thousands of pounds, if it had been preserved to the present time.

The manufacture of CANDLES, which is often connected with soap-making, though it is of comparatively small importance, may yet derive advantages from chemistry, which would repay

the study. Candles should be made without any admixture of oil or grease, and when laid up should be preserved from the action of the atmosphere. If tallows are weak, a part soon becomes converted by exposure to the air to an acid, and this renders the whole, when melted together, unfit for candles. I have heard of some persons who were in the habit of keeping their candles closely covered up in bran, and taking them out only as they wanted to use them. Foreign tallows, which frequently contain a large portion of acid, rendering them inferior to the English, may be purified at a very trifling expense by chemical means; and by the proper application of chemical agents other brown tallows may be rendered beautifully white, and fit for the best purposes.

The mode which naturally presents itself as the best for separating the sebacic acid from tallow, is that of melting it in water containing some alkali; but old tallows may in general be sufficiently purified from their rancidity by melting them upon lime water, and giving a considerable agitation to the whole mixture; for when the water is again suffered to subside, it will be found to be offensive in smell, and to have subtracted most of the impurities of the tallow. Should the tallow, however, be found not to be sufficiently purified, a repetition of this process would completely effect it.

Where great quantities of candles are required, as in large manufactories, mines, collieries, &c. a great saving would arise from the use of carbureted hydrogen gas, which, as the inhabitants of most of our large towns can now testify, produces a beautiful and intense light, much more cleanly than oil or tallow, and at little or no expense. Oils and tallows when burnt with a wick generally produce a portion of soot; but this combustible gas is wholly converted into water and carbonic acid gas, and therefore will soil nothing.

A slight knowledge of the mode of managing the gases would enable the proprietor of all such collieries as may be safely entered with a naked candle, to procure this gas from the small coal, which is *trodden under foot*, and to light up his coal-pits with it with the greatest safety, and at NO EXPENSE. If this mode were adopted, the workmen would be lighted much better than they can possibly be by any other means; thousands of pounds would be annually saved to the community; and the many tons of tallow which are now consuming in these subterranean works might be used in the manufacture of soap; which would tend to lower the price of that necessary article, and render our poor more cleanly and comfortable.

THE BREWING OF FERMENTED LIQUORS, a trade of considerable and increasing consequence, is altogether a chemical process.

Isis and Osiris, it has been said, instructed the countries that were destitute of wine, by what methods they might prepare beer from corn. See Cogan's *Diodorus Siculus*, page 9. When Tacitus speaks of the ancient Germans making wine from *corrupted* corn, he referred, no doubt, to a process somewhat similar to English Brewing. Basil Valentine, an eminent chemist who flourished in the beginning of the fifteenth century, wrote expressly on the different methods of brewing malt liquors. For an account of the curious management by which such kinds of beverage were prepared at the time of the Norman Conquest, the reader may consult *Du Cange Gloss.* tom. ii. page 662. To those persons whose concerns are so large that it would require a princely fortune to purchase even the *utensils*, it must be surely of the utmost importance to acquire some knowledge of the principles of bodies, and of the nature of those changes which take place in the materials upon which they operate. I would therefore say to such persons, Give your sons a chemical education, and you will fit them for conducting, in the best possible manner, the business which you have established. Hence they will learn how the barley, in the first instance, is converted to a *saccharine* substance by malting; how the fermentative process converts the saccharine to a *spirituous* substance; and how the latter, by a continuation of the process, becomes changed into *vinegar*. On these subjects I would recommend a valuable paper on malting in *The Memoirs of the Literary and Philosophical Society of Manchester*, by Mr. Joseph Collier, vol. v. page 265; also A Memoir on Fermentation by Fourcroy and Vauquelin, which has been translated for *The Phil. Mag.*, vol. xxv. page 176, &c. and continued page 219 and the sequel. The nature of fermentation (which until lately was entirely unknown) will be studied and understood; and they will not only have learnt the means of promoting and encouraging this process, but also how to retard or check it, whenever it is likely to be carried too far; so that the scientific brewer will be as sure of uniformly obtaining satisfactory results, as he would if he were operating on matter by mere mechanical means.

In like manner the DISTILLER, the maker of SWEET WINES, and the VINEGAR MANUFACTURER, will all receive benefit from the cultivation of the science we are recommending. When the Romans had possession of this island, the art of distillation was unknown. It is said to have been introduced here in the early part of the reign of Henry II. The latest and best treatise that I have seen on this subject is an octavo volume containing many copper-plate engravings, entitled *Essai sur l'Art de la Distillation*, by L. S. Lenormand, Paris, 1811. Chrysippus, who wrote in the third century before Christ, speaks of the excellence

of the Egyptian vinegar. Such was its strength, that it quickly dissolved the finest pearl Cleopatra had in her possession. *Pliny*, ix. 35. Till the promulgation of the new chemical doctrines, the making of vinegar was carried on like many other trades, in which the makers themselves had no idea of the nature of their own process. An acquaintance with chemistry will teach them many important matters; particularly how it is that the spirituous fermentation is succeeded by the acetous; and how the liquor acquires the substance necessary to produce this change. An account of the theory of Fermentation must be read and understood, before a manufacturer can know how to conduct this process in a scientific manner. I have seen nothing, however, on the art of making vinegar which is more to the purpose than the directions which were published by Boerhaave nearly a century ago. See Dallow's *Translation*, in 2 vols. 4to. London, 1735, vol. ii. page 143. When the vinegar is removed from the action of the sun, it is customary to break up the pipes into small casks and to purchase new wine-pipes to put into their place, from an idea that the *wine* within the wood would add an additional strength to the vinegar; but a knowledge of the cause of the change from the vinous to the acetous fermentation, aided by experience, would inform them that the process will always go on much faster in *old* vinegar casks. When the subject of fermentation is once known, they will soon find by experiment how to oxygenize their wash at the least expense, and in the least possible time. Indeed, when chemical knowledge is more advanced, the process which now requires several months will probably be completed in as many days. The adoption of stoves and some other methods, which might easily be devised, would, I am persuaded, occasion a great saving in this manufactory, besides doing away the necessity of exposing the vinegar in the open air to the sun for so many months, as is the present practice, whereby the casks sustain so much injury as to entail a heavy annual expense on the proprietor of every large work for this article alone. William Homberg, a well known chemist of the seventeenth century, partially filled a bottle with wine that was not at all acid, and having securely corked it and tied it to the vane of a windmill, it became in three days converted into good vinegar. Might not this idea be improved upon, so as to expedite the process in our large manufactories?

The REFINING OF SUGAR is also a chemical process; every branch of which depends upon laws well known to chemists. According to Dr. Anderson, in his *History of the Origin of Commerce*, the refining of sugar was not practised in this country until the restoration of Charles II. It is still conducted by Germans, and little or no improvement has been made in any of the

processes since that time. The separation of the sugar from the molasses; the absorption of the superabundant acid; the granulation of the purified sugar; and the crystallization of candy; will all be conducted most economically, and with the least difficulty, by those who have studied the science with a view to the improvement of their art. An account of a new mode of boiling sugar by means of heated oil, may be seen in the twelfth edition of the *Chemical Catechism*, article SUGAR.

The REFINING OF GOLD AND SILVER may appear to be merely a mechanical operation; but even in this trade the artist cannot produce a single effect which is not attributable to the play of the chemical affinities. To obtain the best and most profitable results in the business of parting, it is necessary that the nitrous acid should be prepared for this express purpose. Some refiners may imagine this to be of no consequence; because they purify it, they say, by means of a solution of silver before they use it. But I can assure such refiners that it is impossible to purify *some* aqua fortis, by means of silver water, as it is usually applied; and that, when such aqua fortis is employed, a considerable loss in the produce of the gold is the inevitable consequence. Besides, there is great reason to believe that a considerable portion of silver is often lost in the process which succeeds that of *quartation*, by the blue water being removed to the verditer-vats before the whole of the silver has been precipitated. A knowledge of chemical principles would suggest to the refiner a mode by which, without the aid of any apparatus, he might in an instant detect even the tenth of a grain of that metal, if left in the solution.

In like manner the reduction of the ores of COPPER¹, LEAD, TIN, ZINC², and ANTIMONY, and the manufacture of BRASS, have all been very materially improved by the application of chemical knowledge, and have supplied sources of wealth to individuals, an immense revenue to the government, and a profitable employment to many thousands of the community.

The manufacturers of GUNPOWDER³, ALUM⁴, COPPERAS, BLUE VITRIOL, and of all other SALTS, would likewise do well to become chemists, before they attempt to bring their several arts to the perfection of which they are capable. The crystallization of salts depends upon so many adventitious circumstances, that no

¹ The copper mines in Cornwall were worked to great disadvantage until Queen Elizabeth invited one Daniel Houghsetter from Germany to instruct her subjects in the art of managing them. For an account of the exclusive privileges which the Parliament granted him, see *Statutes at Large*, in the reign of Queen Elizabeth.

² Notwithstanding the vast stores of Calamine with which this island abounds, we were in the habit of importing all our zinc for the manufacture of brass from India, until Margraaf instructed some individuals in the method of pro-

small share of knowledge is necessary to enable a manufacturer at all times, and in all seasons, to produce the article he intends. Until within these few years the MAKERS OF ALUM bought alkalies of every description. An accurate analysis of alum has now discovered that potash and ammonia are the only alkalies which enter into the composition of alum; and consequently, that during a long series of years large sums have been expended by the manufacturer in the purchase of salts which were comparatively of no use.

The article, however, which is more particularly referred to here, is a refuse product of the soap-works called *black ash*, for which the alum-maker has given from 8*l.* to 15*l.* per ton, though it is composed in a great measure of soda and muriate of soda, neither of which salts is of any use in the preparation of alum. These manufacturers must, surely, have been as careless in their inquiries as the Spaniard of whom Bowles speaks in his *Histoire Naturelle de l'Espagne*, page 80, who on being asked if he knew how the saltpetre was yearly regenerated in his grounds, replied, "I have two fields—in the one I sow wheat, and it grows; in the other I collect saltpetre."

Even science itself is now reaping the benefit of its own discoveries. A few years ago, the MANUFACTURERS OF PAPER were apprehensive that it would be impossible to supply a quantity of that article fit for printing upon, adequate to the increasing demand. Necessity, however, often the source of new inventions, had recourse to chemistry; and in this science, of universal application, found the means of improving the colour of the very coarsest materials;—so that rags which formerly would have been thrown by for paper of the lowest description, are now rendered subservient to the progress of truth, and the promulgation of knowledge. And so easy is the application, that an immense quantity of the materials can be bleached in a few hours; and paper sufficient to print a copy of the largest work in the English language may thus be whitened at the expense of only a few pence.

In like manner it might be shown that the making of BREAD, SUGAR, STARCH, VARNISH, and OIL OF VITRIOL; the felting and

curing it from this ore. According to Pliny (l. xxxiv.) brass was known to the ancients.

³ It is a curious fact, that "upon our discovery of China, we found that nation possessed of gunpowder, a composition which could not have been made without a considerable knowledge of chemistry." See the preface to Delaval's *Inquiry respecting Colours*, page 62.

⁴ The first alum manufactured in England was in the reign of Queen Elizabeth, at Gisborough in Yorkshire, by one Thomas Chaloner, an ancestor of the present R. Chaloner, Esq. M.P. for the city of York. For some particulars of this intrepid man, see Notes to the *Chemical Catechism*, tenth edition, page 100.

fulling of HATS, the refining of SALTPETRE, and the manufactures of SMALTS, ULTRAMARINE, PRUSSIAN BLUE¹, COBALT BLUE, CUD-BEAR², ARCHIL, and other colours³, are all dependent upon chemistry for their improvement and successful practice:—but the mention of a few particulars must suffice.

The success of the starch manufactory depends, in a great measure, upon giving a proper degree of fermentation⁴ to the wheat; it is evident then how much the profit might be increased by a scientific attention to this circumstance.

In making oil-varnishes it is first necessary to oxygenize the oils by means of metallic oxides, in order to give them the drying property. To do this in the best possible way, requires some chemical skill; and, whether the varnish be made with a resin or a gum-resin, it is of the utmost importance to learn the proper solvent for each particular resin, and the best temperature for producing the solution.

Within these few years some manufacturers of hats have introduced a considerable improvement into their manufactories, by treating the fur of the hare and rabbit with a solution of mercury in nitrous acid⁵. As this solution of nitrate of mercury is applied before the fur is removed from the skins, it acts on one side of the hairs only, and renders them crooked, which occasions them to felt much easier than they otherwise would.

In the operation of fulling hat-felts, it has been customary to employ a large proportion of wine lees or tartar; and it was imagined that the consistence and density which this gives to the

¹ A large proportion of the Prussian blue which is made in this country goes to China; the captains of the East India Company's ships take it out at the beginning of the year, and it constitutes a part of the private trade to that country. Though the Chinese are ingenious in the manufacture of a variety of beautiful and permanent colours, they have not yet learnt the art of making Prussian blue.

² This valuable article in dyeing was discovered by a Florentine merchant about the year 1300, which not only enriched himself, but was so very advantageous to the Florentines, that they gave him an honourable title, which was borne by all his family and descendants.

³ When the science of chemistry was little understood, some colours were extremely rare and valuable. Such was the purple of the ancients, which none but the Cæsars were allowed to wear. At the taking of Susa, Alexander the Great found in the royal treasury purple to the value of 50,000 talents, which had lain there 192 years, and still retained its exquisite beauty.

⁴ See Fourcroy and Vauquelin on the Germination and Fermentation of Corn and Seeds, in *Philosophical Magazine*, vol. xxv. pages 176, &c. and 219, &c.

⁵ See Monge's *Annales de Chimie*, tome vi. p. 300. I have good reason, however, to believe, that this preparation of mercury was in general use by the hatters of America for some considerable time before it was employed in Europe for that purpose.

felt, was attributable to the alkali of the tartar; and indeed the author of the French *Encyclopédie* has affirmed that this is the case. But Mons. Chaussier knowing that cream of tartar is a super-tartrate of potash, suspected that it might be the extra tartaric acid which determined the felting; and by direct experiment he discovered this to be the fact, and that any other acid would produce the same effect. Of late years, therefore, the manufacturers have derived considerable advantage from the substitution of diluted sulphuric acid.

The consumption of cobalt blue by the blue potters and manufacturers of porcelain, is very considerable; and until lately it was made only from zaffre imported from Saxony, although it has long been known that cobalt ores were to be found in some of the English mines. Just now, however, a few enterprising men have accomplished their reduction, and a beautiful colour, worth from two to three guineas per pound, and much better than what is usually made from zaffre, has been produced in considerable quantities.

Some other cases of equal importance might also be mentioned, but I flatter myself that the examples already adduced are sufficient to show that chemistry is now a necessary branch of the education of youth. Even the management of a GARDEN⁶ may receive improvement from a cultivation of this science, as it explains the growth of vegetables, shows the use of the different manures, and directs the proper application of them⁷.

The various operations of Nature⁸, and the changes which take place in the several substances around us, are so much better understood by an attention to the laws of chemistry, that in every walk of life the chemist has a manifest advantage over his illiterate neighbour. And it may be remarked, that in case of failure or disappointment in any particular line of commercial manufacture, the scientific chemist has resources as various as the productions of the country in which he lives, to which the uneducated man has no access⁹.

⁶ An Essay of mine on the advantages of employing common salt in horticulture, and which obtained the annual gold medal of the Horticultural Society of Scotland for the year 1819, may be seen in the 3d volume of the *Memoirs* of that Society; or in the *Journal of the Royal Institution of Great Britain*, vol. x. p. 52.

⁷ Natural history in all its branches is intimately connected with chemistry, as it must depend upon this science for any elucidation of the minute properties of those substances, the outward characters of which it describes.

⁸ It was a favourite saying of Lord Bacon's, that "man should observe all the workmanship and the particular workings of Nature, and meditate which of these may be transferred to the arts." Lord Bacon's *Advancement of Learning*, book v. 148.

⁹ A very remarkable instance of a whole nation availing themselves of ad-

Were parents aware of this truth, that sordid maxim *primo vivere, deinde philosophari*, would not be heard; but every youth would be instructed in the first principles of natural philosophy¹ and chemistry, as *the means* of qualifying him for conducting with advantage the concerns with which he might be intrusted. If “knowledge is power,” surely the *love* of knowledge, and a taste for accurate investigation, are the most likely means of conducting to opulence, respectability, and rational enjoyment.

“If,” said a late eminent writer, “we would lay a good foundation for a philosophical taste, and philosophical pursuits, persons should be accustomed to the sight of experiments, and processes, in early life. They should, more especially, be *early* initiated in the theory and practice of investigation, by which means, in a great variety of articles, very young persons may be induced to engage with peculiar alacrity in pursuits truly original².”

Boerhaave, who had a botanical garden of eight acres, and who was so intent upon stocking it with every exotic that he could procure, as once to have styled a present of a few American seeds, “munera auro cariora,”—gifts more precious than gold,—was notwithstanding so captivated with chemistry, that he sometimes spent whole days and nights successively in the study and processes of the art.

The history of the progress of science affords, however, few instances of the advantages of philosophical pursuits, greater than the one which modern times have furnished in the invention of the Miner’s Safety Lamp. During his inquiries respecting the nature of flame, Sir Humphry Davy discovered that gaseous matter can only be made to burn by its being kept at a high temperature, and that its temperature is lowered in a remarkable manner by making it pass through fine wire gauze. Reflecting on this singular fact, it occurred to him, that some advantage might be taken of the circumstance to prevent the explosions in coal-mines; and this led to the construction of that instrument which has already been the means of saving the lives of some

advantages presented to them by chemistry, in a case of the greatest emergency, may be seen in *The Chemical Catechism*, Additional Notes, No. 22, p. 426.

¹ Thales the Milesian, who flourished 600 years before Christ, used to declare that he preferred the study of Natural Philosophy to all other sciences.

Democritus of Thrace, who was contemporary with Socrates, applied himself with so much earnestness to his studies, that he was actually absorbed in philosophy, and declared he would prefer the discovery of *ONE CAUSE* in the works of Nature, to the possession of the whole Persian monarchy.

Paracelsus not only visited learned and scientific men, but frequented the workshops of mechanics, descended into mines, and thought no place mean or hazardous, if it afforded him an opportunity of increasing his knowledge of Nature. Chalmers’s *Biographical Dictionary*, vol. xxiv. p. 85.

² Preface to Dr. Priestley’s *Observations on Air*, vol. iv. London, 1779.

hundred individuals, and which will probably prove a protection to thousands yet unborn. How poor and insignificant are all the honours which rank and power can bestow, when compared with the delightful satisfaction which this great man must derive from the consciousness of having conferred such benefits !

To conclude :—It may be remarked, that it is the necessary consequence of an attention to the science of chemistry, that it gives the habit of *investigation*, and lays the foundation of an ardent and inquiring mind. If a youth has been taught to receive nothing as true, but what is the result of *experiment*, he will be in little danger of ever being led away by the insidious arts of sophistry, or of having his mind bewildered by fanaticism or superstition. The knowledge of *facts* is what he has been taught to esteem ; and no reasoning, however specious, will ever induce him to receive as true what appears incongruous, or cannot be recommended by demonstration or analogy.

ESSAY II.

ON TEMPERATURE.

PART I.—OF NATURAL TEMPERATURE.

AFTER having given some account of the Utility of Chemistry to the Arts, it occurred to me that there would be a peculiar propriety in introducing the following Essays to the notice of the reader, by some remarks on Temperature—as there is scarcely an operation in chemistry, or a process in any of our manufactories, that does not either require a marked attention to the precise degree of heat under which it is conducted, or that would not produce a better result, were this first to be determined by experiment, and made one of the preliminary conditions of the operation.

Besides, if we contemplate the works of Nature, it will be difficult to name any substance that, in the economy of the world, is of equal importance with the matter of heat. What this matter is, or how it produces the astonishing effects which are attributed to it, we know not; nor have philosophers as yet agreed whether it be really a material ponderable substance, or only the consequence of a particular motion excited among the particles of bodies.

Very delicate experiments have been made, which show that bodies when heated do not increase in weight; but these cannot be considered as decisive, on account of the imperfection of our instruments. A cubical inch of inflammable air requires a good balance to ascertain that it has any sensible weight, and a substance bearing the same relation to this, that this bears to platinum, could not perhaps be weighed by any methods in our possession.

So important was this subject considered to be by the late Count Rumford, that in the year 1796 he presented to the Royal Society of London, one thousand pounds three per cent. consols to institute a prize medal to be given once in every two years to the author of the most important discovery on heat, or on light.

The word TEMPERATURE is usually employed to denote the precise state of any region on the face of the earth, with respect to heat and cold; or the condition of any particular insulated body, produced by the operation of caloric¹, or by the partial removal of this wonderful and occult power.

¹ This term (caloric) was introduced not from caprice, but for the sake of giving precision to chemical language, and for the purpose of distinguishing between this peculiar matter itself, and the effects which are produced by it.

In order to furnish a complete Essay on Temperature, it would be necessary to give a history of all the discoveries which have been successively made respecting the matter of heat, and to detail the various experiments which have been performed by the principal philosophers of Europe for the last two hundred years. This, however, would be incompatible with the design of these Essays, and very uninteresting to the class of readers for whom they are more particularly intended.

But, if I can give such a concise and popular view of the general causes of the change of temperature in bodies, as shall enable the most unscientific reader to understand the subject, and shall, at the same time, teach him how to avail himself of the best means of applying his knowledge in the common concerns of life, I shall be abundantly satisfied². To this end it may be most convenient to divide the subject into two branches, and to treat it under the distinct heads of Natural and Artificial Temperature.

The variety of climate in the different regions of the earth, the effects of caloric on animal and vegetable life, and the nature of its agency on combustible substances, will arrange themselves under the first division of the subject; while that on Artificial Temperature will contain a brief detail of a variety of expedients for procuring fire, for modifying the effects of heat and cold, for economizing fuel, and for improving certain operations which have a considerable influence on the success of many of the manufactories of the country.

In regard to CLIMATE, it is not necessary to enter into the disquisition, whether the matter of heat be transmitted to us from an immense globe of fire which we call the sun; or whether it may not be more probable that the necessary quantity of caloric for the wants of the world and its inhabitants, was made inherent in the earth at the time of its formation, and that this sun is an inhabited world, with a phosphorescent atmosphere that perpetually sends forth rays of light, and that these elicit, and, as it were, put in motion the matter of heat belonging to this as well as to the other planets—I say, it is not necessary to adduce arguments in favour of either the one or the other opinion; for this would open too wide a field of discussion, and would be very unsuitable to that brevity which I am anxious to observe, and to that general UTILITY which I have placed before me as the main object to which I aspire.

I am desirous, however, of making a few desultory observa-

² My idea has been exactly expressed by our immortal poet:

“For not to know at large of things remote
From use, obscure and subtile, but to know
That which before us lies in daily life,
Is the prime wisdom.” MILTON.

tions on this point, before I proceed. And in the first place it may be remarked, that the sun's rays appear to have no power of giving heat unless they impinge against a solid body. The focus of the most powerful burning glass, if directed on mere air, does not produce the smallest degree of heat. Thus Mons. Charles, the aëronaut, found the air in the neighbourhood of Paris to be 47° ; and when he had ascended to the height of eleven thousand feet, only 21° , or 11° below the freezing point.

The theory of the sun not being the source of caloric enables us to solve the great difficulty concerning the distribution of heat among the different planetary bodies; for, according to this view, those nearest the sun may have no more than those at the most remote distance. We have only to suppose the quantity of caloric to be proportioned to the distance; and if a *small* quantity exists in the planet Mercury, no more heat may be excited than is done by a *larger* quantity in Saturn.

Moreover it is evident that there must be other causes besides the sun's rays, which operate in the production of variety of climate; for the hottest days are frequently felt in the coldest climates, and the coldest weather and even perpetual snow are found in countries bordering on, or even immediately under the equator.

That we are indebted to the sun for some of the most beneficial effects of caloric, cannot however for a moment be disputed: nor will it be denied that the difference of climate on the various divisions of the earth, is, in a great measure, occasioned by the relative situation of the different regions with respect to that luminary; and that the Author of Nature had an eye to the general felicity, in the curious adaptation of the animal and vegetable creation (in their primitive constitutional qualities and texture of parts) to this great variety of situation and climate.

How strange then must that hypothesis of Mons. Buffon appear, which supposes that the earth and all the other planets were once in a state of fusion; that they are now gradually cooling; and that a time will come when they will have lost so much of their present heat as to be totally unfit to preserve either animal or vegetable existence! As if the Great Architect of this stupendous world had neglected to provide against its degenerating into an useless mass of inert matter.

Fortunately, however, we are not obliged, even on the authority of so great a name, to believe this monstrous and incongruous representation. For all history abounds with circumstantial details, which directly contradict the assertion, and tend, on the contrary, to prove that some of the cold regions of the earth have become much warmer than they were eighteen hundred or two thousand years ago.

The following are a very few of the many instances which might be adduced :

In the Augustan age, the Rhine and the Danube were commonly frozen over during several months of the year; and when the Barbarians overran the Roman Empire, they transported immense weights and innumerable armies across the ice of these rivers¹; a thing which in the present times would be impossible. The rein-deer and the elk, which flourish only in the coldest climates, the former being found, not only in the wilds of Siberia, but on the rocks of Spitzberg within ten degrees of the pole, were in the time of the Cæsars abundant in the Hercynian forest, which was said to be sixty days journey in length, and which covered a great part of that vast country lying between Switzerland and the Black Sea². All the rivers throughout this region were perpetually bound up with ice during the whole winter, which usually lasted for eight months³, and the cold was so excessive that the historians of the time evidently supposed that the countries north of this district must be absolutely uninhabitable. Ovid says that at Tomi, which was seven degrees south of London, the snow continued two years on the ground; and Virgil agrees with him in declaring that the people living on the banks of the Danube were accustomed to cut out their wine with hatchets, and to deliver it to their guests in solid portions⁴. These, and various other instances, incontrovertibly prove that Europe, at least, was formerly much colder than it is at present.

The same change has also taken place on the continent of America. Formerly the people of Guiana, within five degrees of the equator, could not live without lighting evening fires; and though it is not a century since a part of this country was cleared from wood, the heat in that part is already excessive⁵. The parts of North America which have been cleared are also much warmer than they were when the woods were standing.

It has sometimes been imagined that difference in climate is occasioned *solely* by the relative situation of the different countries with respect to the sun; but nothing can be more erroneous, as appears from the state of the Andes which may be adduced as a

¹ Diodorus Siculus, lib. v. page 340, edit. Wessel.

² Cæsar *de Bel. Gal.* vi. 23, &c.

³ Herodotus, lib. iv. § 28.

⁴ " But where Mæotis Scythia's waste divides,
And turbid Ister rolls his yellow tides,
There stalls inclose the herds that never stray,
No grass the field, no leaves the wood array;—
There crystal chains at once whole pools confine,
And hatchets cleave the congelated wine."

Sotheby's *Georgics of Virgil*, book iii.

⁵ Supplement to Buffon's *Natural History*, 8vo. page 346.

complete refutation of this idea; for between the base and the summit of these mountains every degree of temperature may be found. The city of Quito, situated about the middle of one of these, experiences a mild and temperate climate, while the sands beneath it are intensely hot, and the ground above it covered with perpetual snow.

There are so many facts which tend to prove that the climate of a country is not occasioned solely by its situation on the face of the globe, that I am inclined to think many an inhospitable clime might be rendered healthy and uniformly temperate, by the resolute exertions of a good government and an enlightened population.

The country on the borders of the Albany River, and the southern parts of Labradore, are in the same latitude with Great Britain¹; and yet the cold is now so severe, and the snow so perpetually on the ground, that the lands lie entirely uncultivated. The climate of Newfoundland, which is situated still further south than this island, is more like that of the north of Russia than England; and those who have travelled in Canada, which lies in the same parallel of latitude with the finest vineyards of France, assure us that the great river St. Laurence is frozen over for many months, while the correspondent provinces in Europe experience the most genial temperature.

Dr. Robertson, indeed, supposes² that the difference of temperature between certain parts of Europe and similar latitudes in America is equal to twelve degrees, and that a place thirty degrees from the equator in the latter, is as warm as one situated at eighteen degrees from it in the former.

There is also nearly as much variation in the climate of some countries situated near the line. Thus, many parts of Peru are mild and temperate, while the correspondent latitudes on the continent of Africa are scorched by the burning heats of the torrid zone³.

A person accustomed to the examination of the works of Nature, can scarcely avoid being often very much impressed with the consideration of the beauty and excellence of the arrangements which its divine Author has established, for the preservation of the world and the various animated beings which inhabit it. Some of these native and original appointments are contrivances of

¹ According to the observations made at the house of the Royal Society from the year 1772 to 1780, it appears that the mean annual temperature of London is 52°. The greatest usual cold is 20°, and happens in January; and the utmost degree of heat is generally 81°, which commonly happens in July.

² *Hist. of America*, vol. ii. page 472.

³ On the road from Senegal to Podor the heat is frequently 111°. At Pondicherry it has been 113° and 115°. Kirwan *On Climate*, pages 99 and 101.

great wisdom. Of this class, the following appears to me to be a most striking instance, though not often adverted to.

Land is capable of receiving much more either of heat or cold, than water. Saussure, when the air was at 81° , found the Lake of Geneva at the surface was 62° , and at the depth of eighty-seven feet only 55° . In the neighbourhood of Marseilles, Dr. Raymond often observed the land heated to 160° ; but the sea was never hotter than 77° , and even this heat it received chiefly by its communication with land; for in July 1765 he found that the part of the bay next to the land was at 74° , the middle of the bay 72° , and the entrance of the bay only 70° . On the contrary, he frequently observed the earth in winter cooled down to 14° or 15° ; but the sea was never lower than 44° or 45° .

That the land has an effect on the waters of the vicinity, also lowering its temperature, appears from the fact that some of the inland seas of Europe, even of great extent, have sometimes been entirely frozen over. In 1668 the Baltic was so firmly frozen that Charles the XIth of Sweden and his whole army passed over it⁴.

Were it otherwise, and that the waters on the face of the earth had the property of acquiring the same temperature either of heat or cold as the land, the evaporation in summer would be excessive and detrimental; and in winter all navigation would be suspended, and the finny inhabitants of the water would inevitably perish.

Having adverted to this subject, it would be improper to allow it to pass without noticing one or two of the causes which constantly act to modify the temperature of the seas and other large bodies of water. In hot climates, the seas, rivers, and lakes, are prevented from acquiring any thing like the heat of the adjacent lands, by the evaporation which is continually going on at the surface, and which carries off the greater part of the heat as fast as it is received. This principle of evaporation producing cold, has been long understood, and will be explained as we proceed.

On the contrary, in winter, whenever the temperature of the atmosphere is so far reduced as to give the waters a tendency towards freezing, those particles of water on the surface which are first cooled, acquire a greater specific gravity, and sinking within the mass, warmer particles of water ascend to supply their place, which are cooled in their turn, and descend also. Thus a circulation between the surface and the lowest depths of the sea and of other large bodies of water is constantly kept up, which often tends, among other important purposes, to preserve them from

⁴ *Puffend. Hist. Europe. Mod. Univ. Hist.* in 8vo. vol. xxx. page 180. In 1709 the Adriatic was completely frozen over. *Mém. Par.* 1749.

congealing for a long period after the air is reduced to the freezing point.

As the operation of this principle is uniform, it might be expected that the deepest lakes would remain the longest unfrozen; and this is really found to be the case. Near Lochness in Scotland there is a small fresh-water lake on the top of a very high mountain, the water of which never freezes; and near Mohanagh, the seat of Roger Fenwick, Esq., in the county of Cork, there are two small lakes, very deep, that produce trout of an unusual size, and never freeze during the most severe winters, owing to the time between the end of one summer and the beginning of another not being long enough to allow of this circulation being completed¹.

It might however be supposed that whenever this circulation ceases from the increase of the cold, the density of the freezing water would continue to increase also, and that the ice, as fast as it is formed, would be precipitated. But here, Nature, all bountiful, has made a memorable deviation from her usual course; for no sooner is the water cooled down to 40° — 5° , than it not only ceases to increase in density, but, on the contrary, actually becomes of less and less specific gravity, as the caloric is further abstracted by the cold atmosphere.

When this diminution of specific gravity has begun to take place, the water continues enlarging its bulk in regular gradation, until the surface becomes cooled down to 32° , when, if the water be still, a film of ice forms and covers the whole mass. If the cold continues, this covering of ice increases in thickness, and attaches itself firmly to the banks, so as entirely to cut off all communication with the atmosphere, and thus prevent that abstraction of caloric which otherwise would soon convert the whole mass of water into ice.

No person, who has paid even a slight attention to chemical science, can be ignorant of one of its principal axioms, that solids and fluids acquire density by the loss of caloric; it is therefore surely worth while to inquire why this general law of nature has been departed from in this instance, and to consider, what would have been the result had water been subjected to the same law with other bodies?

It has before been remarked, that as water loses caloric it becomes more and more dense until it is cooled down to about 40° ; but if no check had been given to this process, and the density of water had continued to increase until it came down to 32° , the superficial stratum would have continued to descend, followed by others in quick succession, and a body of ice would have first

¹ *Ancient and Present State of the County of Cork*, book ii. chap. iv. p. 264.

formed at the *bottom* instead of at the *surface* of our lakes and rivers. This would have accumulated with such rapidity, that one severe winter would, in all probability, have converted the whole of most of the rivers of Europe into as many solid masses of ice; which, on account of their great thickness, no future summer would have been able to dissolve.

It is certainly extremely curious that the same cause should thus be made to produce effects which, apparently, are diametrically opposite:—That water, within a certain range of temperature, should have its specific gravity *increased* by the loss of its caloric; and then, on a sudden, that the action should be reversed, and its specific gravity *lessened* by the same operation.

It will now be perceived, that this curious contrivance was absolutely necessary for the preservation of the world; and it is pleasing to consider how many inconveniences are avoided by this very simple deviation from the usual course of Nature. The sheet of ice which often covers the small seas, as well as the rivers and the lakes, not only preserves a vast body of caloric in the subjacent water, but when it thaws, the fish are not destroyed by the cold; for not a particle of the cold surface-water can descend, until a change in the temperature of the atmosphere has taken place, so as to raise the temperature of the whole of the water at least ten degrees.

The next branch of our subject embraces the *effects* which are produced on animal and vegetable life by change of temperature; but as these are too various to be even barely enumerated within the compass of an Essay, the mention of a few of the most interesting must suffice.

The first idea which naturally presents itself on this subject is, that nothing but consummate wisdom could have suggested the formation of such an infinitude of animals and vegetables of various natures and properties, and all peculiarly adapted to the various climates in which they are respectively placed.

It is not, however, a little remarkable, that while every climate on the face of the earth, and almost every situation², has a race of animals peculiarly fitted for it, and that can flourish and propagate no where so well as in their native quarter of the world, and in their own appointed localities, man should be so organized

² Messrs. Humboldt and Boppland, in travelling through the province of Quito in South America, perceived live fish thrown up from the bottom of a volcano, in the course of its explosions, and they appeared to be in perfect health, although the water and heated vapour that came up with them, raised the thermometer to 210°; which is only two degrees short of the boiling point. *Recueil d'Observations de Zoologie et d'Anatomie comparée.*

that he can reside, increase and multiply, on every part of the habitable globe.

It is also observable, that while the cold-blooded animals vary their animal temperature with every alteration of the medium in which they live¹, the mechanism of the human body is such, that it is capable of preserving nearly an equable temperament, whatever may be its situation, or however great the transition from its accustomed state, to the highest degree of heat that it can endure, or to the most intense cold; that is, the temperature of the human body is always the same, or nearly so, in all climates.

Of this singular faculty no satisfactory elucidation was afforded until Dr. Crawford, in 1779, published his *Experiments and Observations on Animal Heat*. This eminent philosopher explained it on the well known chemical principle of different substances having different capacities for caloric; on the property that the matter of heat has of becoming latent; and on the fact, which he discovered, that arterial blood has a greater capacity for the matter of heat than venous blood. But that this may be more clearly comprehended by all classes of readers, it may perhaps be necessary to proceed a little further into this part of our subject.

It was formerly presumed that caloric, in whatever state it might be, could always be measured by the thermometer². But the important experiments of Dr. Black and others have shown, that besides the caloric which acts upon, and is appreciable by, the thermometer, there are other portions which are in such close union with most bodies, as to occasion no sensible variation in their temperature. That is, caloric may be so combined with a body, as to have lost all power of affecting the most delicate instrument; yet, when this latent heat is set at liberty, and converted to free caloric, as it is called, this shall be as active, and

¹ To establish the truth of this, many facts might be adduced. Frogs have been frozen so hard, as to chip like a piece of ice, and yet by a careful and gradual increase of temperature have been reanimated. On the contrary, worms of the species of *Tænia* have been taken alive out of the body of a boiled carp.

² There are four different thermometers employed in Europe. This often occasions much inconvenience. Ours has the scale of Fahrenheit, the zero of which commences at 32° below the point at which water freezes; and between this and the point at which water boils, it is divided into 212 degrees. The late Dr. Kirwan proposed that the use of all these thermometers should be discontinued, and a general one constructed, beginning at the congelation of mercury, and terminating at the ebullition of water, and to be divided into 250 degrees. The late Dr. Murray of Edinburgh suggested that it would be convenient to form a scale whose extreme points should be the temperatures of freezing and boiling quicksilver, and to divide this scale into 1000 degrees. Kirwan *On the Temperature of different Latitudes*, 8vo, 1787, preface, page vii. Murray's *Chemistry*, 8vo, 1809, vol. i. page 139.

as energetic, as though it had never been confined³. A single example will be sufficient to adduce, by the repetition of which any one may satisfy himself of the truth and propriety of this distinction.

Put about half an ounce of cold water into a small phial, and add to it, *very gradually*, about an equal measure of oil of vitriol, gently shaking the phial after every addition of the acid. The consequence of this will be, that the water will immediately begin to give out its latent caloric; and when so much oil of vitriol has been added as is equal to double the measure of the water, the mixture will assume a degree of heat superior to that of boiling water.

In regard to the operation of this principle in the act of respiration, Dr. Crawford thus explained it: The oxygen, said he, which is one of the component parts of atmospheric air, has a large portion of caloric chemically combined with it, and a great part of this caloric is taken up by the blood, every time that the atmospheric air passes through the lungs; the internal surface of which, according to anatomists, is equal to the external superficies of the whole body; and on this *extended* surface it is that the venous blood, through the medium of a thin pellicle, is exposed to the influence of the respired air. Every time we make an inspiration, the bone of the breast rises and the diaphragm sinks. By these two contrivances room is made for a pint and a half, or more, of atmospheric air, at every drawing in of the breath.

How then is it that the lungs are not injured by this great accession of the matter of heat? This is a difficulty which Dr. Crawford has explained by the discovery, that arterial blood has the property of arresting this caloric, and of chemically combining with it—that is, of absorbing it in the same way as ice at 32° absorbs caloric, and is converted into water without becoming warmer, in the least degree, by the addition⁴: and that when this blood flows from the arteries to the veins, the case is altered, and, by some unknown contrivance, its capacity for caloric is then lessened, and what was latent or combined caloric in the arteries, becomes free caloric, or sensible heat in the veins⁵; and as these

³ A luminous explanation of the doctrine of latent heat may be seen in Dr. Robison's preface to Dr. Black's *Lectures*, 4to. p. 34, &c.

⁴ An example of a contrary effect may be found in the conversion of ice into water. Let one pound of ice at 32° be dissolved in one pound of water heated to 172° , and it will be found that 140 degrees of heat have disappeared, and become latent in the fluid, which assumes a temperature of 32° only; whereas, if a pound of water at 172° be mixed with a pound of ice-cold water at 32° , the temperature of the mixture will be exactly 102° , which is the mean of 32° and 172° . Ice requires 140 degrees of caloric to give it fluidity, and this it receives without the least augmentation of temperature.

⁵ If the reader have an opportunity of referring to the third chapter of the *Chemical Catechism*, twelfth edition, pages 59—64, he will find several instances adduced, whereby the difference between latent and free caloric is explained.

branch out in infinite ramifications to every extremity of the body, the genial warmth is conveyed through these channels to every part. And when the blood returns to the lungs¹, its former capacity is restored, and it again loads itself from the atmospheric stores, and distributes the caloric, as before, to every even the most minute vessel in the animal system.

When this theory was first published, it was naturally asked, What becomes of the azote, which is also a component part of atmospheric air? and whether a great portion of the caloric would not be required to preserve this azote in the state of gas, so that it might be expelled from the lungs when the oxygen was separated from it? And that as a part of this oxygen takes up carbon from the blood, whether the remainder of the inhaled caloric would not be necessary for the formation of carbonic acid gas, which, it is well known, is also thrown off in the act of respiration?

But here another remarkable contrivance presents itself, and it is one that is equally necessary to the uniform preservation of animal heat. This I cannot explain with more conciseness, than by transcribing the following note from the *Chemical Catechism*, Chapter II. page 52.

“It is not simple azote or nitrogen, which is thrown out of the lungs in respiration, but *nitrogen gas*; and it has been imagined that, when atmospheric air is decomposed by the lungs, part of the disengaged caloric is required for the nitrogen, to preserve it in the form of gas: but it is a very curious fact, that nitrogen gas and carbonic acid gas have less capacity for caloric than any other gaseous substance. It is a general characteristic of the gases, that they absorb a large portion of caloric to preserve them in a gaseous form. Yet one of these gases has less capacity for caloric than many liquids, and the other (nitrogen gas) less capacity than even ice.”

When this beautiful theory for the explanation of the production of animal heat was first proposed, most of the philosophers of Europe acquiesced in it, and it continued to be generally received for many years after the death of its learned and ingenious author. Some considerable physiologists have, however, of late years offered several objections to Dr. Crawford's reasoning, especially Mr. Brodie, whose paper was published in the *Philosophical Transactions* for 1812; but none of these writers have as yet favoured the world with a theory that is less objectionable, or that will explain the phenomena attendant on respiration and on the evolution of animal heat, in a more satisfactory manner.

¹ The blood of the veins is black, or purple; but as it passes through the lungs it deposits charcoal, and becomes, when it enters the arteries, a bright scarlet.

We shall, however, at all events, be justified in saying, that the arrangements, whatever they may be, for the production of animal heat, and for the preservation of life, are equally operative in every climate and in every situation in which man is likely to be placed: for, not to advert to other causes, it may be remarked, that in climes intensely cold the atmospheric air is more condensed, and consequently more caloric is taken in at every inspiration. And be the temperature of the air what it may, a thermometer with its bulb under the tongue or buried in a wound in the flesh always indicates a heat of 97° or 98° .

In many of the habitable parts of the Russian empire the cold is often sufficiently intense to freeze mercury; although, as is well known, that fluid metal does not become a solid until it be reduced to the temperature of 71 degrees below the point at which water freezes²: and it is observable, that when men have been accustomed to cold climates, so as to know the precautions³ necessary to be taken, they can endure more severe cold than even this, without sustaining any permanent injury.

Many of the natives of Great Britain make annual voyages to Greenland, and stay there during the fishing season, where the cold is greater than most people can imagine. Some idea of it may, however, be formed from the account we have of the masses of ice which are generated there, and float occasionally from thence into the Atlantic Ocean. "These mountains of ice," says Dr. Troil, "which are often seen fifty feet or more *above* water, are at least nine times⁴ the same depth *below* water⁵. Frequently these immense masses are left in shoal water, fixed, as it were, to the ground, and in that state remain many months, nay years, undissolved, chilling the whole of the atmosphere for many miles round."

The *Stockholm Memoirs* for 1757 mention a fact which fully

² Some idea of the very low temperature of frozen mercury may be derived from the circumstance, that if a lump of it be dropped into a small quantity of water at the boiling point, it will abstract the caloric with such rapidity that the mercury will instantly become fluid, and the hot water will at the same moment be converted into ice.

³ One precaution necessary to be observed in such situations, is, not to handle any metallic body; for, if an instrument or utensil of iron, or any other metal, which had been exposed to the cold atmosphere, were touched, a sensation would be felt like that of burning, and the part would, in all probability, be blistered.

⁴ Mr. Boyle found by experiment, that a cylinder of ice floating in water of the same specific gravity as that of which it was made, could rise only one tenth of its height above the surface of the water. Boyle's Appendix to *The History of Cold*, p. 16.

⁵ The account which Pennant in his *Arctic Zoology* has given of the ice mountains at Spitzbergen is grand and interesting. The "collision," says he, "of the great fields of ice, in high latitudes, is often attended with a noise that, for a time, takes away the sense of hearing any thing else; and the lesser, with a grinding of unspeakable horror."

corroborates this statement of the effect of mountains of ice or snow on the atmosphere. "When," says the writer of that paper, "a north-west wind blows on the mountains of Norway, it occasions a thaw; but when it has passed these mountains and entered Sweden, it produces the most intense cold."

Moreover, Mr. MacNab, when in Hudson's Bay, experienced a cold so intense as to sink the spirit thermometer to 82° below the freezing point, which, if his instrument did not deceive him, was eleven degrees below what is required for freezing mercury.

On the other hand, whenever an animal is placed in a medium the temperature of which is considerably high, the usual change of arterial into venous blood does not take place; consequently there will be no evolution of caloric, and the animal heat will not rise much above the natural standard: but the problem has not yet been solved, how high is the degree of heat which the human frame can endure without injury.

Sir Joseph Banks and Sir Charles Blagden once attempted to ascertain this, and for some time actually breathed an atmosphere, in a room prepared by Dr. Fordyce, which was fifty-two degrees higher than that of boiling water. It is related in the *History of the Academy of Sciences* for 1764, that the oven-girls in Germany often sustain a heat of from 250° to 280° , and one of these girls once breathed in air heated to 325° of Fahrenheit for the space of five minutes.

During the time that Sir Joseph Banks and Sir Charles Blagden submitted themselves to Dr. Fordyce's experiment, the temperature of their bodies was not at all raised; though their watch-chains, and every thing else metallic about their persons, were so heated that they could not bear to touch them¹. The thermometers which hung in the rooms always sunk several degrees when either of the experimentalists breathed upon them or touched them; and to prove that there was no fallacy in the degree of atmospheric heat shown by the thermometer, "we put," says the reporter, "some eggs and a beef steak upon a tin frame in the room, and in 20 minutes the eggs were taken out roasted quite hard, and the beef steak was overdone in 33 minutes."

Water placed in the same room did not, however, acquire a boiling heat until a small quantity of oil was dropped into it, when it soon began to boil briskly. The evaporation from the surface of the water had prevented it from acquiring the heat of 212° ; but when that surface became covered with a film of oil, the evaporation could not go on, and ebullition commenced².

¹ "The heat of metals at the temperature of 120° is scarcely supportable; water scalds at 150° , but air may be heated to 240° without being painful to our organs of sensation." Davy's *Elem. of Chem. Philosophy*.

² Sir Charles Blagden's relation of these very interesting experiments may be seen in the *Phil. Trans.* for the year 1775, pages 111 and 484, &c.; and a

That evaporation produces cold, is a very familiar axiom in chemical science: and this principle is operative also in the regulation of animal heat; for, whenever the human body becomes oppressed by heat, if it be in a state of health, perspiration commences, and this carries off the superabundant caloric as fast as it is produced.

These effects of perspiration, which are so extremely beneficial in the animal economy, arise from a well known chemical principle, viz. that water cannot be converted to vapour until it has combined with a very large portion of caloric. Thus, in all oppressive heats, the fluids of the human body are determined to the surface, from whence they escape in the gaseous form, carrying off with them that superabundant heat which otherwise would soon have become insupportable.

That perspiration actually does operate in this way, may be readily conceived by those who know that a thermometer plunged into steam indicates only the same degree that it would in boiling water, although the steam contains nearly one thousand degrees more of caloric chemically combined with it, and that, owing to its being in a latent state, it is not appreciable by the thermometer.

It is by this combination with caloric that steam is enabled to preserve its gaseous form, in which state it occupies a bulk 1800 times greater than that of water; and this is the only way in which we can account for the loss of that continued stream of caloric which is perpetually passing, and often for many hours, through the bottom of an evaporating vessel, or other boiler of water, when placed over an intense fire; because, if the fire be the same, the water actually admits as much caloric after it boils, as it did before, although that which it now receives does not, in the least, augment its temperature.

The temperature of boiling water is usually 212° , and the constant evaporation prevents it from ever acquiring a higher temperature, however intense may be the fire that is placed beneath it. In like manner, the natural temperature of the human body is about 96° or 98° ; and whatever may be the degree of heat to which it is exposed, the animal perspiration always carries off the superabundant quantity, and prevents it from ever acquiring a temperature much beyond the usual standard.

These multiplied contrivances for the preservation of life, by maintaining an uniform animal temperament, were surely not the offspring of chance; their peculiar adaptation shows them to be a part of the great scheme of unerring Wisdom, effected

series of experiments by Dr. Crawford, on the power that animals possess of producing cold, will be found in *Phil. Trans.* for 1781, page 479.

by a Being who wills the convenience and felicity of his creatures.

There is still some intricacy respecting the nature of the operation of caloric on combustible substances; and this will not seem surprising when we consider, that all the theories of combustion which were promulgated before the time of Lavoisier are now deemed extravagant, or at least very unsatisfactory. A short sketch, therefore, of the very ingenious theory which this eminent philosopher published about the year 1775, to explain the phenomena of combustion, may perhaps be acceptable to those persons who have had no opportunity of investigating the subject.

“Some bodies (said he) are combustible, others are incombustible. If a body which is formed of combustible materials be heated to a certain degree in atmospheric air, combustion will commence, and its affinity for oxygen will be so great that it will abstract it from the atmosphere. Should the combustible substance be placed in favourable circumstances, with the free access of atmospheric air, this perpetual accession of oxygen will keep up the combustion until the whole of the combustible matter becomes saturated with oxygen, and then, in popular language, it is said to be consumed.”

The heat, in this process, generally arises from the decomposition of the oxygen gas of the atmosphere; but he thought it probable that the light¹ and the flame in most cases proceed from the combustible body itself, and that combustion is a mere chemical process, a double decomposition, in which not only two compound bodies are separated into their original elements, but two new compounds are always formed. For while the light, which is extricated from the burning substance, unites with the caloric of the oxygen gas, and produces what is called fire, the oxygen itself combines with the base of the combustible, and forms a new incombustible substance. This incombustible matter will be either water, an acid, or an oxide; or a compound of two or more of these substances.

In this view of the subject, combustion can never take place in vacuo. Atmospheric air, or some other compound containing oxygen, must, as he asserted, be present in every instance of combustion; and this he explained by reference to a variety of direct experiments.

Since the time of Lavoisier, however, several objections have been urged to this theory; most of which have been detailed by Professor Brande in his *Manual of Chemistry*, vol. i. page 317,

¹ For an account of the colours of the light which proceeds from different combustibles, the reader may consult Dr. Fordyce in the *Phil. Trans.* for 1776, and the Rev. W. Morgan in *Phil. Trans.* for 1785.

and by Dr. Ure in his *Dictionary*; and these, together with the discovery that chlorine and iodine will support combustion, neither of which contains oxygen, have entirely confuted the French assertion that oxygen, or some of its compounds, must be present in every case of combustion. We are therefore now compelled to come to the conclusion, "That combustion cannot be regarded as dependent upon any peculiar principle or form of matter, but must be considered as a general result of intense chemical action."

It must, notwithstanding, be observed that nothing has occurred to refute the generally received opinion, that in all the ordinary cases of combustion, it is the oxygen of atmospheric air, and that alone, which supports the combustion.

The necessity for the presence of oxygen in the more familiar cases of combustion is so clearly exemplified in a certain operation on cotton goods, not universally known, that I conceive it may be useful to advert to it. The process to which I allude, and which is very common in Lancashire and other calico-printing districts, is called singeing, and has been contrived for the purpose of taking off all the ends of the threads and other downy filaments that are usually attached to the piece, and of giving the whole a smooth surface.

To effect this, several pieces of calico, previously fastened together by their ends, are lapped smoothly round a large wooden roller, from which, by a regular motion, they are passed over a large semicircular piece of cast iron, which, by means of a furnace placed immediately beneath it, is constantly kept at a full red heat.

Calicoes, muslins, dimities, fustians, &c. are treated in this manner, and the subsequent bleaching takes out any stains which they may have contracted from the iron; all of which is more minutely described in the *Essay on Calico Printing*.

To a stranger, this may seem a very destructive operation (and no one can witness it for the first time without astonishment); but by the quickness and regularity of the motion, and by the uniform pressure of the cloth upon the hot iron, the combustion that would otherwise take place is prevented, and nothing is burnt but the loose threads that rise above the surface of the fabric. The peculiar effect that is here produced, and how the cloth is protected from the red-hot metal, may be thus explained.

The uniform *pressure* of the cloth upon the heated cylinder, keeps that part of it which is directly over it in close contact, so that there is no space for the intervention of any more atmospheric air than is just sufficient to occasion the combustion of the mere superficial filaments of the cotton or linen; and this is the only effect which the manufacturer is desirous of producing.

This process, which is now universal with the printers of cotton goods, explains why our housewives cannot get up their home-spun linen with so neat a face as that which is sold in the shops. There are some intelligent laundresses, however, who are fully aware of the principle on which the above-named process is founded; for, when about to iron their clothes, they dismiss all anxiety about the precise degree of heat; as they well know that, however hot their flat-irons may be, if they press them with all their force upon the linen, and that the linen be smoothly spread, it will never sustain any injury.

It has already been remarked, that in the ordinary cases of combustion which occur in consequence of, and are supported by, the constant presence of oxygen, during the process the oxygen combines with the base of the combustible: but there is another axiom of equal importance to be impressed on the memory of all those who are likely to be engaged in any kind of chemical operations, which I believe was first proved by direct experiment by Lavoisier, viz. "That every body increases in weight by the operation of combustion." This may perhaps require a little explanation, but it is a law of Nature to which there is no exception.

Even the slow combination of oxygen with a body increases its absolute weight, as is well exemplified in the formation of the metallic oxides; the metals always acquiring additional weight by being converted into oxides. Thus, by exposing melted lead to the action of the atmosphere, under a peculiar management, red lead is formed, and a ton of pig lead will yield 22 cwt. of red lead.

But where complete combustion takes place, this increase is generally more considerable: thus, if 100 pounds of zinc are burnt in a proper apparatus, flowers of zinc will be formed, and the product will be 125 pounds. If spermaceti oil be burnt in a way that the product can be examined, it will be found that the whole is converted to carbonic acid and water, and that every hundred ounces of the oil have produced 130 ounces of water. In like manner, if phosphorus be burnt by a rapid combustion, it will attract oxygen from the atmosphere, and become phosphoric acid, and every pound of the phosphorus thus employed will produce more than two pounds of acid.

It would be fruitless to enumerate more instances, though I thought it right to mention a few obvious examples in passing, because I have met with many intelligent people who had never annexed any idea to combustion but that of absolute destruction; and yet I know of no subject connected with the economy of the world, which it is of more importance to investigate, or which is better calculated to give us exalted conceptions of the arrangements of that Being who hath not only formed a perfect whole,



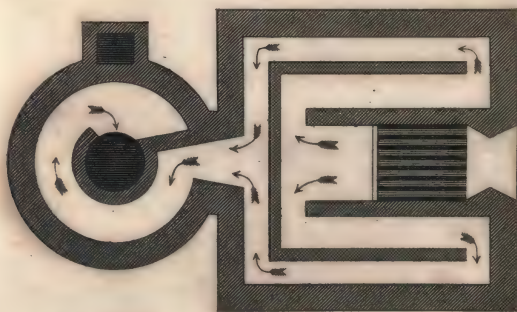
CHEMICAL ESSAYS.

Plate 2



*Improved
Rum Still.*

Fig. 8.



- A. The Still. B. Preparing Vessel. C. Perpendicular Pipe. D. The Chimney. h. The Man hole. c. The Safety valve. d. The Stop cock to cut off the communication.*

and pronounced every part to be in itself good, but has so constituted things that none of the materials which he has employed in the construction of the world can ever be lost or destroyed.

Metals, by means of oxygen, may be converted to pulverulent and even impalpable substances; but, whenever the oxygen is abstracted, every character of the original metal will be restored. All sorts of combustible substances may be employed for the necessary purposes of increasing temperature: the caprice of man may commit many invaluable, as well as worthless substances, to the flames; or the lightning of the heavens may involve a whole district in one general conflagration, in which every thing combustible shall be reduced to ashes:—but let it be remembered, that the act of combustion only separates the particles of bodies, and puts them in a state to form a variety of new combinations equally useful and necessary in the order of the Universe.

And shall we be told that such a state of things is the effect of chance? Certainly not. Sir H. Davy has well remarked, in opposition to such absurdity, that “in the Universe nothing can be automatic, as nothing can be said to be without design. An imperfect parallel,” says he, “may be found in human inventions. Springs may move springs, and wheels, indexes; but the motion and the regulation must be derived from the artist. Sounds may be produced by undulations in the air, undulations of the air by vibrations of musical strings; but the impulse and the melody must arise from the master.”

PART II.—OF ARTIFICIAL TEMPERATURE.

HAVING proposed in this part of the Essay to treat of certain expedients for increasing and diminishing temperature, I shall begin with an account of the means which have been employed by different nations, and in different periods of the world, for producing fire.

FIRE has been known in some part or other of the world in all ages. In ancient times it was always employed in the rites of religion; it consumed the burnt offerings of the Patriarchs; it was kept continually burning in the Jewish tabernacle; it was looked upon as the origin of life¹, the soul of the world², the

¹ Fire was so generally considered as the image of life, that *lighted torches* were usually placed in the hands of the newly married; and at their deaths *extinguished torches* were placed upon their tombs. *Essai sur le Feu sacré*, &c. 8vo. Amsterdam, 1768.

² The fable of Prometheus, who stole fire from heaven to animate his man, seems to have been founded on this idea.

symbol of Deity; and, considering it as the visible sign of an invisible Being, it has, from time immemorial, been actually worshipped by the Persians, and by some other Asiatic nations. The sacred fire of the Vestal virgins, among the Romans, was beheld by them with little less than adoration. Numa built a temple to Vesta, the goddess of fire, which in after ages was rebuilt with great magnificence.

Notwithstanding, according to Pliny, fire was for a long time unknown to some of the ancient Egyptians; and when Eudoxus, the celebrated astronomer, showed it to them, they were absolutely in raptures.

The Persians, Phenicians, Greeks, and several other nations, acknowledged that their ancestors were once without the use of fire; the Chinese confessed the same of their progenitors. Pomponius Mela, Plutarch, and other ancient authors, speak of nations, who at the time they wrote knew not the use of fire, or had but just learnt it. Facts of the same kind are also attested by several modern relations.

The inhabitants of the Marian Islands which were discovered in 1521 had no idea of fire. Never was astonishment greater than theirs, when they saw it on the descent of Magellan on one of their islands. At first they believed it to be a kind of animal that fixed itself to and fed upon wood. The inhabitants of the Philippine and Canary Islands were formerly equally ignorant. Africa presents us, even in our own days, with some nations in this deplorable state of ignorance¹.

The production of fire by collision, and the use of flint and steel², were probably known long before the time of Pliny; though the more ancient method of procuring fire was by rubbing two dry sticks one upon the other with violence³. The Indians fasten two pieces of wood together, and then putting another stick between them, they turn the latter swift like a wimble, and thus make the whole take fire. In Apulia they wrap a cane within some cords, and then drawing the cords backward and forward, the cane becomes ignited by the motion⁴.

Fire is also to be procured FROM THE SUN by means of a double convex lens, a concave mirror, or by a combination of a

¹ Goguet's *Origin of Laws, Arts, and Sciences*, vol. i. page 72.

² The Laplanders begin their contracts of marriage with the fire and flint; for fire with them is the author of life; and the flint, say they, is eternal, for the treasure of fire within it never fails. *Scalig. Exerc.* 16, § 1. Jonston, page 33.

³ A series of experiments on the heat produced by the attrition of different woods against each other may be seen in Nicholson's *Journal*, vol. viii. page 218; together with a table constructed on the said experiments.

⁴ Jonston's *History of Nature*, page 34.

number of plain mirrors⁵. It was by some one of these expedients that Archimedes contrived to set fire to the ships of the Romans during the siege of Syracuse. That this account is not fabulous, as some writers have imagined, is rendered probable, from the effects which have been actually produced by these contrivances in later ages. Father Kircher, and his pupil Schottus, visited Syracuse for the express purpose of investigating the truth of this story; and they proved by direct experiment that Archimedes, by a combination of mirrors, might easily have destroyed the fleet of Marcellus at the distance at which the ships must have lain from the walls of the city; and also the possibility of the success of Proclus, who is said to have destroyed a fleet at Constantinople in the same manner.—*Phil. Trans.* vol. *xlvi.* page 621. The following instances will be sufficient to enumerate.

At the beginning of the last century Mr. Tschirnhausen, a member of the Royal Academy of Sciences, made several burning glasses, which were each three or four feet in diameter, and had a focus of one inch and a half diameter at the distance of twelve feet. One of these, which was convex on both sides, and weighed one hundred and sixty pounds, was used by M. Homberg, who communicated the result of his experiments to the Academy, and announced the following facts.

“All sorts of wood,” says he, “though ever so hard or green, will be fired by this instrument in a moment. Water in a small vessel will boil immediately. Tiles, slates, pumice stones, grow red in a moment, and vitrify. Any metal, put into the crevices of a coal, melts in a moment. Lead and tin volatilize entirely. The ashes of herbs and wood become transparent glass in an instant⁶.”

Another instrument and one that was still more powerful was constructed in the year 1773, under the direction of M. de Trudaine, and placed in the garden of the Infanta at the Louvre. It was composed of two large glasses, each four feet in diameter, joined at the edges so as to hold alcohol. These glasses, which were without flaw, were two thirds of an inch thick, and formed two portions of a sphere of eight feet radius, leaving between them a vacuum capable of containing thirty-five French gallons of liquid. The focus of this instrument was at the distance of ten feet ten inches, when filled with alcohol; at eleven feet eleven

⁵ By these means wood may be burned to a coal, even under water. Hoffman, with the assistance of a concave mirror made by Hoessen, fused the Hungarian asbestos into glass in three seconds. Hopson's *Translation of Weigleb*, page 66.

⁶ *The History of the Works of the Learned*, 4to. London, 1702, vol. *iv.* page 655.

inches when filled with distilled water; and at seven feet when filled with liquid turpentine. With this apparatus all the effects already mentioned were easily produced, and even the clippings of bar-iron were melted in an instant¹.

We are informed, however, by Mons. Buffon, who expended a very considerable sum in the construction of different instruments for concentrating the rays of the sun, that the only way by which the sun's rays can be made to produce an intense heat at a great distance, is by the combination of a considerable number of plain mirrors, so disposed as to throw numerous images of the sun upon the same spot².

One of these instruments, which consisted of 360 plain mirrors, each eight inches long and six inches broad, mounted on a frame eight feet high, produced the following very powerful effects:

When twelve of the mirrors only were used, light combustible substances were kindled at the distance of twenty feet. At the same distance a large vessel of tin was melted by forty-five of these mirrors, and a thin piece of silver with 117 of them. With the entire machine all the metals and metallic minerals were melted at the distance of forty feet: and when the sky was clear, wood was kindled by it even at the distance of 210 feet.

In appreciating the comparative value of concave and plain mirrors, Mons. Buffon remarks, that as at the distance of fifty feet the focus, or space in which all the images coincide, is about seven inches broad, metals may be assayed by it, and other curious experiments made in the large way, which it is impossible to execute with concave mirrors, in which the focus is inconveniently near or weak, and generally a hundred times less than that produced by this machine.

Among other purposes for which this instrument may be employed, the author has stated that it might be used with advantage in the manufacture of salt, by producing a quick evaporation of the salt-water, without the expense of fuel. An assemblage of twelve mirrors, each a foot square, will, he says, be more than sufficient to give a boiling heat to the liquor contained in shallow pans constructed for this purpose.

There are difficulties however in applying this instrument to purposes of general utility which must not be concealed. A cloud passing over the sun during some processes would be a great inconvenience; and when the sun does shine in its full splendour, the motion of the earth will prevent the focus from ever being kept for a minute at a time on one spot.

¹ *The History and Memoirs of the Royal Academy of Sciences at Paris, for the years 1774 and 1777.*

² *Phil. Trans.* No. cccclxxxiii. pages 493 and 495.

In describing the burning glasses made on the continent, I have been guilty of a great omission by hitherto neglecting to notice the burning mirror belonging to Sir Isaac Newton, which consisted of seven concave glasses, each of a foot in diameter; and the glass lens made by Mr. Parker, of Fleet-street, London, at an expense of 700*l.*, which was doubtless the most powerful burning lens ever constructed. The zero of Wedgwood's pyrometer was fixed by the inventor at the lowest red-heat visible in daylight; the greatest welding heat of iron by that instrument is 95°, and the extremity of the scale is 240°: but the power of the lens, estimated by this pyrometer, was found to be 1096°, which is a temperature that was never before obtained by any human being. In addition to these few particulars, I am desirous of stating that a very circumstantial account of this wonderful instrument has been drawn up by Mr. Parker, jun. for Rees's Cyclopædia, where it will be found, under the article "Burning Glass," in vol. v. part ii.

ELECTRICITY is also a means that may be mentioned when treating of the various methods of increasing the temperature of bodies, as it is capable of producing powerful effects. The electric matter collected by the friction of a glass plate or cylinder upon a prepared cushion is received on a metallic conductor, as it is generated; and from thence it is conducted into a number of glass jars coated with tin-foil. Electricity is best excited by rubbing the cushion with an amalgam of tin and zinc. The excitation seems to depend upon the ready oxidizement of the metals which form the amalgam; for such metals as are not easily oxidized produce no electricity.

By the discharge of one of these electrical batteries, the combustion of various substances may be effected; animal life may be destroyed; and wires of the different metals will be melted in an instant. But notwithstanding these powerful effects, the electric matter may be thrown *gradually* upon the human body without producing any mischief or inconvenience whatsoever; as is constantly practised in cases of medical electricity. To this silent and harmless employment of the electrical fluid, one of our modern poets refers in the following lines:

"For if on wax some fearless beauty stand
And touch the sparkling rod with graceful hand,
Through her fine limbs the mimic lightnings dart,
And flames innocuous eddy round her heart."

By VOLTAIC ELECTRICITY, or galvanism, much more powerful effects may be produced in igniting various substances, and in melting metals, than have ever been occasioned by simple electricity. These, however, depend much on the size and the na-

ture of the apparatus; and though most persons may be acquainted with this property of galvanism, it is impossible for any one to form an adequate idea of the power which may be acquired by an extensive apparatus, in which there is a proper combination of number of plates, and an extended surface, unless he actually witnesses some of the effects produced by it.

“The grandest combination,” says Sir H. Davy, “ever constructed for exhibiting the effects of extensive surface *alone*, was made by Mr. Children; it consists of twenty double plates four feet by two; of which the whole surfaces are exposed in a wooden trough, in cells covered with cement, to the action of diluted acids. This battery, when in full action, had no more effect on water, or on the human body, than one containing an equal number of *small* plates; but when the circuit was made through metallic wires, the phænomena were of the most brilliant kind.”

“A platinum wire of one thirtieth of an inch in thickness, and eighteen inches long, placed in the circuit between bars of copper, instantly became red hot,—then white hot;—the brilliancy of the light was soon insupportable to the eye; and in a few seconds the metal fell into globules¹. Points of charcoal ignited by this power, produced a light so vivid, that even the sunshine, compared with it, appeared feeble.”

“But the most powerful combination that exists, in which number of alternations is combined with extent of surface, is that constructed, by the subscriptions of a few zealous cultivators and patrons of science, in the laboratory of the Royal Institution. It consists of two hundred instruments, connected together in regular order, each composed of ten double plates arranged in cells of porcelain, and containing in each plate thirty-two square inches; so that the whole number of double plates is 2000, and the whole surface 128,000 square inches.

“This battery, when the cells were filled with sixty parts of water mixed with one part of nitric and one part of sulphuric acid, afforded a series of brilliant and impressive effects.

“When pieces of charcoal, about an inch long and one-sixth of an inch in diameter, were brought near each other, within the thirtieth or fortieth of an inch, a bright spark was produced, and more than half the volume of the charcoal became ignited to whiteness; and by withdrawing the points from each other a constant discharge took place through the heated air, in a space equal at least to four inches, producing a most brilliant ascending arch of light, broad and conical in form in the middle.

¹ To form an adequate idea of the power of this apparatus, it should be recollected that platinum cannot be melted in the most intense heat of an air furnace, nor in a smith's forge, unless oxygen gas be employed; and yet by the silent action of galvanism it became, in this instance, fused in a few seconds.

“When any substance was introduced into this arch, it instantly became ignited; platinum melted as readily in it as wax in the flame of a common candle; quartz, the sapphire, magnesia, lime, all entered into fusion; fragments of diamond, and points of charcoal and plumbago, rapidly disappeared, and seemed to evaporate in it, even when the connexion was made in a receiver exhausted by the air pump; but there was no evidence of their having previously undergone fusion.” *Elements of Chem. Phil.* p. 151.

The CLOUDS may be considered to be another source from whence man has the means of procuring fire. The first idea of the identity of lightning and electricity occurred to the mind of Dr. Franklin in the year 1752; and in the month of June in that year, he elevated a kite for the purpose of ascertaining the fact, and on the first trial he had the satisfaction of finding his conjecture verified and the discovery complete².

In the following year the experiment was repeated in France, and on a large scale, by Mons. Romas, which fully demonstrated the powerful effects of elevated metallic conductors in drawing off the electric matter.

The kite which he employed had a wire interwoven in the hempen string, and the following were some of the signs of electricity which it exhibited soon after its elevation in the atmosphere. “Electrical sparks three inches long and a quarter of an inch thick were drawn at the distance of a foot from a tin conductor, connected with the apparatus, the snapping of which was heard at 200 paces. On the falling of a little rain, the appearances increased amazingly, and a continual rustling noise was heard, like that of a small forge bellows.”

The remainder of the account which Dr. Priestley has given of these very interesting experiments³ is too long to be introduced here; but I have no hesitation in saying that those of my readers who may have an opportunity of seeing the work, cannot fail of being highly gratified by its perusal.

By this discovery of Dr. Franklin’s we have learnt how to secure houses and other more elevated buildings, and ships at sea, from damage by lightning; and are taught that a very small metallic conductor, if elevated above the highest part of an edifice, and connected with the earth, is capable of conveying a very large quantity of electric matter from the clouds to the earth, without noise, and without leaving any signs of its having been present.

Those who may be desirous of repeating the experiments with

² Priestley’s *History of Electricity*, 4to. London, 1767.

³ *Ibid.*

an electrical kite, ought, however, not to attempt the thing without the utmost caution, and a thorough knowledge of the science of electricity, lest they should share the fate of Professor Richman, who through mere inadvertence lost his life, in the midst of his family, during a series of experiments similar to those of which we are now speaking.

This ingenious and indefatigable man, who was professor of natural philosophy at Petersburg, had elevated an insulated metallic rod, and prepared a considerable apparatus to collect the aërial electricity, as Dr. Franklin had previously done at Philadelphia; and as he was observing with Mr. Sokolow, engraver to the Royal Academy at Petersburg, the effects of the electricity upon the balls of his electrometer, during a thunder storm on the 6th of August, 1753, he approached too near the conductor, and was instantly struck dead by the side of his philosophical friend, who received no injury. An engraving and ample description of the apparatus employed may be seen in the 48th vol. of the *Phil. Trans.*; also a drawing of the apartments of the house, marking the room and the exact situation in which the professor stood when he received the fatal stroke.

The deceased was attending the usual meeting of the Academy, when hearing it thunder at a distance, he hastened home, in company with Mr. Sokolow, to witness its effects upon his apparatus, and in less than an hour he became a corpse.

The explosion which attended this dreadful catastrophe, was as loud as the report of a pistol; the stroke was given at a foot distance from the rod; and from the description of Mr. Sokolow, the electrical spark which struck the professor must have been of a size several inches in diameter. The metallic rod was broken in pieces; and the melted fragments being thrown upon Mr. Sokolow's clothes, left the mark of their form and dimensions upon them.

The professor had seventy rubles of silver in his left coat-pocket which were not in the least altered. But a clock which stood in an adjoining room was stopped, the door of one of the chambers of the house was broken, and the ashes which lay upon the hearth were forced from thence into the middle of the room.

Mrs. Richman, on hearing the loud stroke of the thunder, hastened into the chamber, and found her husband past sensation, sitting upon a chest, which happened to be placed behind him, and leaning against the wall, which situation must have been occasioned by his falling back upon receiving the electrical charge. He was no sooner struck than killed. There were not the least appearances of life. The surgeons opened a vein of the breathless body twice, but no blood followed. They endeavoured to

restore sensation by violent friction, and by other expedients, but in vain¹.

COLLISION is another means of procuring fire. When fire is produced by **COLLISION**, particularly when flint and steel are the media, it arises from the sudden extrication of the *latent* caloric which is forced out by percussion, then becoming free and perceptible to our senses. It was first suggested by Mr. Hume², and his opinion is now found to be correct, that oxygen exists in a very large proportion and in a most condensed state in flint and all other siliceous stones. Were I, therefore, to hazard a theory upon the phenomena that take place in this instance, I should say,—the latent caloric thus set free had been previously combined with the steel, and perhaps with this condensed oxygen; and that the new compound, the spark which flies off, and is oxide of iron, requiring less latent heat for its composition, permits what is now superfluous to become *free* and active, and to pass to the tinder, gunpowder, or any other combustible substance to which it may be exposed.

This application of flint and steel to each other has lately been employed not only for procuring fire, but for another very important purpose.

The late Mr. Spedding, who was an engineer to some large collieries in the North of England, having observed that the coal-damp could only be kindled by flame, and was not liable to be set on fire by red-hot iron, invented a machine, in which, while a steel wheel is turned round with very rapid motion, flints are applied to it, and by the abundance of sparks emitted, the miners are enlightened, and enabled to carry on their work in places where the flame of a lamp or candle would be likely to occasion dreadful explosions. Without some invention of this sort, the working of such mines would have been utterly impracticable³.

PHOSPHORUS may be mentioned as another agent by which fire may be produced extemporaneously, at any hour and in any

¹ *Phil. Trans.* vol. xlviii. page 765, and vol. xlix. page 61.

When RICHMAN rear'd, by fearless haste betray'd,
The wiry rod in Nieva's fatal shade;
Clouds o'er the Sage with fringed skirts succeed,
Flash follows flash, the warning corks recede;
Near and more near HE eyed with fond amaze
The silver streams, and watch'd the sapphire blaze;
Then burst the steel, the dart electric sped,
And the bold Sage lay number'd with the dead!

² In the first edition of *The Chemical Catechism*, 8vo. 1806, page 151, and *Philosophical Magazine*, vol. xxx. page 165.

³ A more particular account of this expedient may be seen in *The Tradesman's Magazine*, vol. ii. page 445.

season. All that is necessary is to rub a few grains of it for a second or two, with a match or other small piece of wood, upon a piece of cork, when inflammation will quickly take place, and continue till the whole of the phosphorus be consumed. This peculiar substance is chiefly of animal origin, though it be still doubtful whether it is not originally derived from the mineral kingdom, and thence passes to vegetables, and so on to the animal system, where it is most abundant.

Phosphorus was discovered either by Brandt or Kunkel about the year 1669. The product of its combustion is either phosphorous or phosphoric acid, according to the quantity of oxygen absorbed, and to the mode in which the combustion has been conducted.

Fire may also be procured with great facility from a saline compound called CHLORATE OF POTASH, formerly HYPER-OXYMURIATE OF POTASH. If this salt be intimately mixed with any of the highly combustible substances, and the salt be then decomposed, fire and combustion will be the consequence.

A preparation of this sort may very conveniently be made by mixing some of the salt with about an equal portion of loaf sugar, both in fine powder. This is a mixture which may be kept ready prepared and preserved in a phial for any length of time, with perfect safety. Whenever fire is required, all that is necessary is to put a few grains of this mixture upon a bit of tile or on a plate, and then to drop upon it the most minute quantity of concentrated sulphuric acid, which will occasion an immediate burst of flame, increasing in size until the whole mass enters into actual combustion.

A composition of this kind has been lately employed instead of sulphur for coating the ends of matches; and these are more convenient for procuring fire, or an instantaneous light, than any thing which has ever before been offered to the public. In using them, all that is necessary is to dip the coated end of one of them into sulphuric acid, or into a phial of asbestos impregnated with that acid, and it will take fire immediately. The asbestos is put in merely to prevent the acid from spilling, as cotton is put into a common inkstand. The fire in this case is produced in consequence of the decomposition of the chloric salt by the sulphuric acid, which seizes the base of the salt, and liberates the chloric acid, which also becomes decomposed, and occasions this curious phenomenon.

By mixing this salt with other combustibles, such as sulphur and charcoal, in proper proportions, a preparation will be formed which will inflame merely by percussion or friction; and an ingenious Scotch chemist, the Rev. Alexander Forsyth of Bel-

helvie, has taken advantage of this property of the chlorate of potash, and employed it in the manufacture of a new kind of gunpowder, for which he obtained a patent, and which, for priming the guns of sportsmen and some other purposes, is preferable to common gunpowder. An eighth of a grain of it is sufficient for priming a fowling-piece or a musket, and this of itself makes a very loud report¹. Before Mr. Forsyth obtained his patent, M. Berthollet had proposed to manufacture gunpowder with this salt for the use of the French army; but no sooner did the workmen begin to triturate it than it exploded violently, and occasioned the death of several persons. Notwithstanding this accident, gunpowder made with chlorate of potash was some time afterwards employed by the French army in one of their campaigns.

To these methods of procuring fire may be added that of COMPRESSION. It is a general maxim in chemical science, that extension and rarefaction occasion cold, but that condensation and compression generally produce heat.

This principle is well exemplified in a machine erected at one of the mines in Hungary. In this apparatus the air within a large cylinder is very forcibly compressed by a column of water 260 feet high. Therefore, whenever a stop-cock which is attached to the lower part of the cylinder is opened, the compressed air rushes out with great violence, and its expansion is so sudden and considerable that the moisture which was contained in the compressed air is immediately condensed, and falls in a shower of snow. *Phil. Trans.* vol. lii. page 547.

Some time ago a soldier in the French army discovered that light and heat may be produced merely by the compression of atmospheric air. This curious discovery has been acted upon in various parts of Europe, and is likely to become applicable to a variety of purposes. By adapting a moveable air-tight cap to the bottom of a common syringe, and placing within it a small piece of perfect tinder, and then depressing the piston with a sharp quick motion, heat will be produced sufficient to inflame the tinder. The use of the screw cap at the end of the syringe, is not only to render the instrument air-tight, but for the purpose of receiving the fungus or the tinder to be placed within it.

These syringes are now sold by most of the philosophical-instrument-makers in London; and since their exhibition, it has been proposed to make walking-sticks furnished with similar sy-

¹ A more particular account of this new gunpowder, and which I received myself from the patentee, will be found in *The Chemical Catechism*, Additional Notes, No. 56: and an account of several curious experiments with the chlorate of potash, will be found in the twelfth edition of the same work, pages 191 and 505.

ringes, (though for this purpose these syringes must be inverted,) and so contrived that a single stroke of the walking-stick on the ground would be sufficient to inflame the tinder, and afford the traveller a light in any emergency.

There is another mode of procuring fire, viz. by PERCUSSION. Nothing is more common in some countries, where fuel is dear and fires are not kept up during the night, than for a smith to procure a light in the morning by laying a bar of iron across an anvil and hammering it incessantly till it become hot enough to set fire to tinder. Here, a portion of the caloric which is naturally latent in the iron, and tends to give it malleability, is forced out by the continued hammering, and becomes free and efficient heat.

FRICTION, which seems to be only a succession of percussions, will also produce intense heat. Mr. Thomas Wedgwood held the edge of a piece of window-glass against the surface of a revolving grit stone, and the part in contact with the stone became red hot and threw off particles which fired gunpowder. *Philos. Trans.* for 1792, pages 45 and 270. Since then Count Rumford suspended a metallic cylinder within a quantity of cold water measuring eighteen pints, and caused it to revolve, pressing against a boring instrument, at the rate of thirty times in a minute; and in the course of two hours and thirty minutes it generated heat enough to make the water actually boil. *Phil. Trans.* for 1798, page 80.

It is also possible to produce combustion by the mere MIXTURE of some fluids. Thus, if certain proportions of nitrous and sulphuric acid be poured into the essential oil of turpentine, a rapid combustion and inflammation will be occasioned. This, however, is not a very safe experiment, unless it be conducted with caution and prudence.

It may also be mentioned, that if either POTASSIUM or SODIUM be placed upon ice, fire will be produced, and the metal by this combustion will be converted to an alkali.

Combustion often occurs spontaneously by the DECOMPOSITION OF WATER; of this we have many instances. Hay, clover, weld, or other vegetables, if put up in ricks before they are properly dried, are very apt to ferment, and occasion spontaneous combustion. Substances that are thoroughly impregnated with animal or vegetable oil, when laid up damp and in large heaps, are also very likely to take fire of themselves from the decomposition of the water and the oil. This happens sometimes to painted oil-cloths, and likewise to woollen cloths¹, which have been laid up

¹ There is a singular account of the spontaneous decomposition of a fabric of silk, in the *Philosophical Magazine*, vol. xvi. page 92.

moist, and in heaps, without having the oil removed which had been employed in dressing them. There are also examples of cotton taking fire by being improperly laid up²; and the spontaneous firing of a mixture of lamp-black and oil is well known³. I believe it is also no very uncommon thing for buildings to be burnt down in consequence of quick lime being incautiously stored in them, and water getting access to it.

Again, *peat* laid up in very large heaps for fuel is disposed to take fire; and in coal countries it is universally known that if pyritous coal be stacked without having the martial pyrites previously picked out, there is great danger that the first shower of rain may produce heat enough to set fire to the whole mass⁴.

This combustion of pyritous coal is probably the cause of many of the subterranean fires which appear in every quarter of the globe. Near Baku in Persia, the inflammable vapour which issues from the earth is so considerable that the inhabitants burn their lime by its means. There is a caravansary built on the spot, and in this live twelve Indian priests and other devotees who worship this fire, which, according to their traditions, has burnt many thousand years. "It is a very old vaulted building, and in its walls are many chinks, whereto if a candle be applied, the fire catches instantaneously, and runs wherever the chinks communicate. They have hollow places in the house fitted to their pots, where they boil without any other fuel; and instead of candles they stick reeds into the ground, from the tops whereof, upon applying fire thereunto, a white flame comes forth, and continues to burn without consuming the reeds, until they think proper to extinguish it, by putting little covers over them for that purpose." *Phil. Trans.* vol. xlv. page 296. Other curious particulars respecting this subterranean fire may be seen in Mr. Jonas Hanway's *Account of his Travels through Persia*.

Dr. Plot speaks of a district near the Staffordshire collieries which was on fire in his time⁵. This spot I have myself visited

² Dr. Henry accounts for the fires which have sometimes happened in cotton-mills, from the waste cotton, employed to wipe the oil from machinery, having been laid in heaps sufficiently large to occasion combustion. Henry's *Chemistry*, vol. ii. page 162.

³ There have been instances in which carburetted earths, being mixed with linseed oil for the purpose of making paints, entered spontaneously into a state of combustion. *Gentleman's Magazine*, vol. xxi. page 71, and vol. xxii. page 82.

⁴ Dr. Plot relates the case of a person at Ealand in Yorkshire who piled several cart-loads of martial pyrites in a barn, of which the roof being faulty, the rain came upon them, set fire to the building, and occasioned an alarm for the safety of the whole town. Plot's *Staffordshire*, page 142.

Dr. Jorden mentions that a heap of coals once took fire at Puddle Wharf, London, in consequence of pyrites being mixed with them. Jorden *On Mineral Waters*, chap. 14.

⁵ Plot's *History of Staffordshire*, chap. iii. page 141, § 53.

more than once, and the mass of coal within the bowels of the earth is still burning, and probably will not cease for ages yet to come. The poor inhabitants of that neighbourhood call it the *fiery ground*, and felicitate themselves in living so near it, as many of them make considerable sums of money, early in the year, by the produce of their gardens, which are always some weeks forwarder than any other in that part of the kingdom. Some of the esculent vegetables flourish surprisingly on this spot.

There is a fountain near Grenoble in Dauphiné; another in Transylvania; a third near Chermay, a village in Switzerland; a fourth in the canton of Friburg; and a fifth not far from Cracow in Poland, the waters of which give out gases that will take fire and burn. Campbell's *Political Survey*, vol. i. page 73.

I have mentioned elsewhere that His Majesty's ship *Ajax* is supposed to have been destroyed in the Mediterranean entirely by the sudden combustion of a heap of pyritous coal, then on board for the use of the ship. I also noticed that a friend of mine had a serious accident from the spontaneous inflammation of a mixture of hyperoxymuriate of potash, charcoal, and sulphur.

All such accidents may be explained, by referring them to the decomposition of water, and the inflammation of its hydrogen. But there are instances on record of another kind of spontaneous combustion, which is not so well understood, viz. that of the human body absorbing oxygen with such rapidity as that the whole became silently consumed to ashes¹; and this, independently of any outward agent, to which the commencement of the combustion could possibly be attributed.

Several cases of this kind have been described and well authenticated; though it is remarkable that this has never been known to have happened to any but females, and all these were persons who had long indulged themselves in an inordinate use of spirituous liquors².

The means which have been employed in different parts of the world for MODIFYING the effects of HEAT AND COLD, have been so various, that I can only attempt to enumerate a very small proportion of them. But I shall select those which I do not consider to be very generally known, or such as may probably be applied, though in a different way, to some useful purpose in this country.

¹ There is an account of a great variety of cases of spontaneous combustion, in the 18th volume of the *Phil. Mag.* extracted from a memoir by Mons. Bartholdi in one of the volumes of the *Annales de Chimie*.

² The curious case of the Countess Cornelia Zangari, also of Bandi of Cesena, of Grace Pet at Ipswich, whose body is said to have been burnt to a cinder, and of a woman at Paris, may all be seen in *The Gentleman's Magazine*, vol. vi. page 647, and *The Philosophical Transactions*, vol. xliii. page 447.

If we begin with that part of the subject which refers to the MODIFICATION of HEAT, or the reduction of temperature, it must be remarked that this is often effected on different principles, according to situation and circumstances.

In some cases the principle of producing cold by EVAPORATION is resorted to. Thus in India, where the apartments are separated from their courts by curtains instead of walls, slaves are employed in perpetually sprinkling these curtains with water, the evaporation of which, when constantly kept up, will reduce the temperature of the rooms ten or fifteen degrees.

The alcarazas of Spain for cooling wine act on the same principle. These, which are very porous earthen vessels, are prepared for use by soaking them in water for a considerable time, so as to saturate them with that fluid. Within these earthen jars vessels containing the wine are introduced, and the perpetual oozing and evaporation of the water cool the interior of the vessel, and consequently reduce, in some measure, the temperature of the wine or other liquor placed within it.

These, however, at least all that I have seen, are ill calculated for the purpose; for, being so much larger than necessary, a sheet of air of the temperature of the room envelops the wine bottle, and prevents the proper action of the alcaraza upon it; whereas, if they were made perfectly cylindrical, instead of being bulged, and no larger than just sufficient to admit a bottle of wine within them, they would be much better refrigerators than those which are usually sold for this purpose.

This principle of cooling by evaporation is well understood by the caravans who cross the great desert of Arabia. These people have occasion for a large quantity of water, which they carry with them on camels, in bottles of earthen-ware, and which, in passing over the burning sands of that country, would become very disagreeably hot, were it not for the following expedient, which is universally adopted by them. When they lay in their stock of water, each bottle is infolded in a linen cloth, and some of the company are appointed to keep these cloths constantly wet during the journey; by which means a perpetual evaporation is produced, and the contents of the bottles are preserved at a cool and refreshing temperature. Athenæus relates, that in Egypt the pitchers filled with water, which had become warm by standing all day long in the sun, were kept continually wet during the night by servants destined to that office; and in the morning, to preserve the water at the cool temperature to which this expedient had reduced it, the pitchers were bound round with straw. *The Deipnosophists*, iii. page 124.

In like manner, in the nights in Bengal, when the temperature is not below 50°, by the exposure of water in earthen pans upon

moistened bamboos, thin cakes of ice are formed, which are heaped together and preserved under ground by being kept in contact with bad conductors of heat.

In performing some delicate chemical experiments, the application of this principle may be found extremely useful. Thus, any fluid body which has been heated by mixture or otherwise, may, in a few minutes, be brought to the desired temperament by frequently wetting the containing vessel with ether, which, by the rapidity of its evaporation¹, and consequent abstraction of caloric, instantly lowers the temperature.

Should any one doubt the efficacy of evaporation in producing cold, let him suspend a thermometer in the air, and, having wet the bulb with ether once or twice, notice its operation as indicated by the scale of the instrument.

Evaporation is also a drying as well as a cooling process. When I have wanted a bottle in haste to be thoroughly dry, for taking specific gravities or any other nice philosophical purpose, after washing it with water, and draining that out as well as I could, I have rinsed it with a little ether, and it has been dry in an instant.

But the more ancient, and perhaps the most universal mode of reducing the temperature of bodies, was by means of ICE and SNOW. That these were used for this purpose in the time of Solomon, we have the testimony of some of the most ancient writings²; and we are told that Alexander the Great, when he lay before the besieged city of Petra, having an eye to the delicacies of his table, caused thirty trenches to be dug, and filled with snow, which was defended from the sun by oak branches, and preserved for a long time in the state required³.

The celebrated Abbé Nollet, who drew up a memoir on the means of supplying the want of ice in warm countries, advises the keeping of wines and other potable liquors in the following manner, in preference to keeping them in wells, cisterns, or cellars. He recommends the digging a hole in the earth about four feet deep, in which the liquor should be placed in bottles, covering them over with a foot of earth, dug from the bottom of the hole, and moistened with a little water, after which he advises the covering up the mouth of the hole with a plank, strewed over with new dug earth⁴. In adopting this method, it will be essen-

¹ For an account of an expeditious mode of producing ice by the evaporation of sulphuric ether, see *Phil. Trans.* for 1795, or *Monthly Review*, New Series, vol. xxi, page 299.

² "As the cold of snow in the time of harvest, so is a faithful messenger to them that send him: for he refresheth the soul of his masters." *Proverbs* xxv. 13.

³ *Athenæi Deipnos.* iii. 124. Beckman, vol. iii. page 344.

⁴ *History of the Royal Academy of Sciences at Paris*, for the year 1756.

tial not only that the liquor should be put into the thinnest bottles, but also that these should be of such a form as to afford the greatest quantity of surface to the refrigerating agent. Hence several thin glass bottles will be much better than one larger bottle of thick glass.

Ice and snow in hot countries being applicable to so many useful purposes, it was natural for mankind to devise some expedient whereby they might have these articles in all seasons. Hence ice-houses were built, but the era of their invention is not known. That the ancient Romans were acquainted with them is evident from the writings of Pliny, who passes this severe censure upon them:

“Hi nives, illi glaciem potant, pœnasque montium in voluptatem gulæ vertunt: servatur algor æstibus, excogitaturque ut alienis mensibus nix algeat⁵.”

It appears, however, that the practice of cooling liquors, at the tables of the great, was not usual in any country of Europe, excepting in Italy and the neighbouring states, before the end of the sixteenth century: and there is a direct testimony on record, that in the middle of that century there were no ice-cellar in France⁶. However, before the end of the seventeenth century the luxury of ice was very common in France; for about that time there were many persons who were professed dealers in snow and ice; and Quintine, the celebrated French gardener, relates that once, when no ice could be procured on account of the great mildness of the preceding winter, the merchants at Hamburg sent a ship to Greenland for a load of it, by which they acquired great profit⁷. In 1676 there were not less than two hundred and fifty shops, in Paris alone, for the sale of liquors of different sorts cooled with ice⁸.

In regard to the receptacles for ice, I have not met with any account of the mode in which the ancient Romans constructed their ice-houses, and therefore I can give only a few particulars respecting the modern practice.

At Leghorn and in other places in that neighbourhood, they lay the bottom of their ice-pits with a thick covering of corn chaff; and as the ice is placed within them, the chaff is brought up all round the sides, and when the pits are full they are well covered up with the same article. Whenever it is necessary to

⁵ Lib. xix. c. 4. Martial in one of his epigrams sports with it thus:

“Non potare nivem, sed aquam potare rigentem
De nive, commenta est ingeniosa sitis.”

MART. xiv. Ep. 117.

⁶ Beckman's *History of Inventions*, vol. iii. page 356.

⁷ *Instruction pour les Jardins*, Paris, 1730, 4to, i. p. 263.

⁸ Beckman, vol. iii. p. 362 and 378.

remove any of the ice to a distance from these pits, it is infolded in similar chaff, and is thus preserved from melting. *Phil. Trans.* vol. i. page 139.

Sir Robert Barker has given a very particular account of the method of making ice at Calcutta and other parts of the East Indies lying between $25\frac{1}{2}$ and $23\frac{1}{2}$ degrees north latitude, where natural ice is never seen. But I shall refer my readers to the paper itself for particulars¹; and also to any of the modern Encyclopedias for an account of the present mode of building ice-houses in England, as a full description of them is not compatible with my present plan.

Olearius, in an account of his journey to Muscovy and Persia, relates that at Ispahan the inhabitants have conservatories, which they furnish with solid pieces of ice of a good thickness, only by pouring water at night, at certain intervals, upon a sloping floor of freestone or marble, where it becomes frozen and attached to the former coat of ice, and in two or three successive nights is brought to a very considerable thickness.

The late Mons. Fourcroy, when treating of temperature, remarks, that “chemists often avail themselves of the privation of caloric, in order to prevent the effect of chemical action; to impede the too powerful energy of solutions, combinations and decompositions; or to prevent those spontaneous changes which do not fail to take place in certain compounds, if they remain for a time exposed to a temperature sufficiently elevated to favour the mutual action of their principles. By these means, namely, by a cold temperature, vegetable and animal substances are preserved; and thus it is that an ice-house is scarcely less useful to the chemist than a furnace at its different degrees of heat.

“In Tibet the inhabitants adopt the practice of preparing their meat by extreme cold. The process is extremely simple. They kill, clean, and strip the animal of his skin; he is then placed upon his legs in a commodious place, and left exposed to a free access of frosty air, until all the juices in his body are completely dried up, and the whole becomes one uniformly stiffened substance. It is then in a fit state for carriage to any part of Tibet, and for keeping to any season of the year. No salt is used in the preparation. I had supplies of this prepared meat, during all the time I remained at Teshoo Loomboo, which had been cured in the preceding winter. It was perfectly sweet, and I was accustomed to eat heartily of it, *without any further dressing*, and at length grew fond of it. It had not the appearance of being raw, but resembled in colour that which has been well boiled. It had been deprived of all ruddiness, by the intense cold².

¹ *Phil. Trans.* vol. lxx. page 252.

² Turner's *Embassy to Tibet*, 4to, London, 1806, p. 301.

Captain James, whose ship was frozen up all the winter in one of the coldest regions of the world, writes thus: "We got up our five barrels of beef and pork, and had four butts of beer and one of cyder, which God had preserved for us: it had lain under water all the winter, yet we could not perceive that it was any thing the worse³.

As it is well known that some decompositions take place at a temperature below 32° , which cannot be effected at one more elevated, it might be worth while for a chemist who has access to an ice-house, to institute a series of experiments, in order to determine the affinities of the simple substances, and some of their compounds, when submitted to the action of intense cold.

Ice-houses are also employed with advantage by many of our butchers during the summer months in preserving meat⁴. The Hon. Mr. Boyle relates that the physician to the Emperor of Russia assured him that he had had the venison of elks sent him unsalted, and yet untainted, out of Siberia, which is some hundreds of leagues distant from Moscow, and that beef and other flesh well frozen would keep for a very long time uninjured; and that it will have lost none of its natural flavour, provided it be very gradually and thoroughly thawed, before it be dressed for the table⁵.

We know that from the salmon fisheries in Scotland and the north of England, the fish are sent to the metropolis, during the greater part of the season, packed with ice, in boxes about four feet long and eighteen inches deep. When packed, the ice, which is previously broken as small as bay-salt, is put over them and beaten down as hard as can be without bruising the salmon. In this manner they are kept perfectly fresh for two or three weeks.

There is another way of modifying heat which has not yet been adverted to, and which is comparatively of late invention. I refer to the use of certain SALINE BODIES, which absorb a large portion of caloric during their solutions, and consequently produce a great degree of cold.

The salt which was originally used for this purpose was nitre, and the Italians were the first people by whom it was employed. About the year 1550, all the water as well as the wine drunk at the tables of the great and rich families at Rome was cooled in this manner. It was customary to place the bottle containing the wine within a larger vessel of water, and into this they gra-

³ T. James's *Journal*, page 74.

⁴ "At Spitzburg the extreme cold will suffer nothing to putrefy and corrupt, insomuch that buried bodies are preserved entire for thirty years, and inviolated by any rottenness." Bartholinus *de Usu Nivis*, cap. xii.

⁵ *Experiments on Cold*, 4to, London, 1683, page 85.

dually put as much saltpetre as is equal to one-fourth or one-fifth of the weight of the water, and during its dissolution the bottle was driven round by the hand with a quick motion on its axis, in one direction¹.

After this, other salts were employed; and Lord Bacon, who died in 1626, asserted that, by a mixture of snow with common salt², he could freeze water³. In the *Mineralogy* of Aldrovandus, first printed in 1648, it is said "that it was usual in countries where fresh water was scarce, to make deep pits in the earth, to throw rock-salt into them, and to place in them vessels filled with water, in order that it might be cooled."

When snow is mixed with common salt, both substances soon become in some measure liquid⁴. Now it is well known that solids can never become fluid without heat being absorbed, and consequently cold produced: therefore the abstraction of that portion of free caloric from the materials which is necessary to produce fluidity⁵, is sufficient to account for the formation of ice in a fluid that is immersed in it.

Towards the latter end of the seventeenth century, Mr. Boyle made experiments with various kinds of salts and other substances for reducing the temperature of water, and in the year 1683 published his "*Experiments and Observations touching Cold*;" a work of great labour and ingenuity⁶. By these researches he discovered that either common salt, alum, vitriol, sal ammoniac, lump-sugar, oil of vitriol, nitrous acid, caustic ammonia, or alcohol, when mixed with snow, had the power of freezing water, and thus laid the foundation for the modern discoveries respecting frigorific mixtures.

About this time the use of a mixture of snow and common salt had become very common in several countries in Europe. It was by a mixture of this sort that Fahrenheit, in the year 1710, fixed the zero of his thermometer, supposing this was the *extreme* point of cold, but a long period intervened before any

¹ Beckman, vol. iii. page 363.

² The iced creams are now, I believe, usually made by plunging the vessel of cream into a mixture of bruised ice and common salt.

³ *Historia Vitæ et Mortis*, § 44. *Silva Silvarum*, cent. i. 83.

⁴ The windows in Russia are frequently covered with frost, and it is a common practice to clean them with salt. By rubbing the glass with a sponge dipped in common salt, the ice quickly dissolves, and the glass becomes immediately transparent.

⁵ Mr. Boyle so early as the year 1683 noticed that no salt mixed with snow would produce ice, "unless it helps the snow to dissolve faster than else it would." *History of Cold*, title i. § 13.

⁶ He describes how snow may be made artificially; he also speaks of a useful syphon which may be made with ice. *Additional Experiments*, pages 14 and 16.

facts of importance were added to those which Mr. Boyle had published on this subject.

The art of making ice was for many years practised only as an amusement, and no one suspected that it would ever be applied to such important purposes, both of science and luxury. Like gunpowder, and many other valuable discoveries, it was at first considered to be of very trifling consequence.

Some modern demonstrators in anatomy have availed themselves of the use of frigorific mixtures in the dissection of the brain and the eyes of animals. To the great Boyle they are probably indebted for the idea; for in his *History of Cold* he says, "Many years since, I made an experiment of freezing the eyes of oxen and other animals, whereby the fluid humours of that admirable organ may be so hardened, as to become tractable, even to unskilful dissectors. So I did with the brains of animals, which, though too soft to be easily dissected, may by congelation be made very manageable⁷."

In the beginning of the seventeenth century, drinking cups made of ice⁸, and iced fruits, were brought to table; and before its conclusion the French began to congeal all kinds of well-tasted juices, which were served up as refreshments at the tables of the great and wealthy.

In the year 1621 Barclay's *Argenis*, an interesting romance, was published at Paris, and its author places on the table of Juba, in the middle of summer, fresh apples for Arsidas, one half of which were incrustated with transparent ice. A bason of ice filled with wine was also handed to him, and he was informed that to prepare all these things in summer was a new art. "Two cups," says the author, "made of copper were placed the one within the other, so as to leave a small space between them, which was filled with water: the cups were then put into a pail, amidst a mixture of snow and unpurified salt coarsely pounded, and the water, in three hours, was converted into a cup of solid ice, as well formed as if it had come from the hands of the pewterer."

A few years after the publication of the book just mentioned, a new beverage was introduced, called *lemonade*, which soon came into high repute, and was recommended by physicians against putrid diseases. About the year 1660 an Italian from Florence, having learnt a process of freezing confectionery, which had been before employed only by jugglers, conceived the happy idea of converting such beverage entirely into ice. This found a ready sale, and was the occasion of so great an increase in the

⁷ Boyle's *History of Cold*. Postscript, page 253.

⁸ Very easy and simple directions for making ice-cups for drinking of wine in summer, will be found in Mr. Boyle's *History of Cold*, title xiv. page 137.

number of sellers of lemonade, that in the year 1676 the *lemonadiers* of Paris were formed into a company, and received a patent from the Government.

In the beginning of the next century the process of congealing water by the mixture of salt or nitre with ice and snow was so well known, that it was then become, in Paris and elsewhere, a common amusement for children, who had a trick of placing a jug containing a mixture of snow and saltpetre on a table over which water had been poured, and agitating the mixture with a stick until the jug became firmly frozen to the table. The Duke de Chartres went often to a certain coffee-house in Paris to enjoy a glass of iced liquor. One day, in the year 1774, the landlord, we are told, to the great satisfaction and surprise of the Duke, presented him with his coat of arms formed of eatable ice.

However, after the investigations of Boyle, no scientific experiments on the production of artificial cold seem to have been made till the subject attracted the attention of Dr. Blagden, Mr. Cavendish, Mr. Lowitz, and Mr. Richard Walker, who were at that time separately engaged in the same pursuit. The latter gentleman, however, was the first person who was able to produce ice in the middle of summer, merely by the solution of saline substances, without the aid either of ice or snow.

Having been thus successful, Mr. Walker pursued his experiments, and on the 20th of April 1787 actually succeeded in his attempt to freeze mercury. At the commencement of the experiment the temperature of the mercury was 45° ; and as its freezing point is at 39° below zero, he obtained, without using a particle either of snow or ice, a reduction in temperature amounting to no less than 84 degrees.

This experiment, by which mercury was first seen in Great Britain in a state of solidity, was made at Oxford, Mr. Walker being at that time apothecary to the Radcliff Infirmary in that city.

The apparatus which he used in this experiment consisted of four pans, progressively diminishing in size, placed one within another, and these, when thus arranged, were all placed in a vessel still larger. Some of the materials for producing the reduction of temperature were put in *each* of these pans, and others in bottles in the spaces between them, so that those in the outermost pan received, before being put together, the cold produced by the frigorific mixture in the larger vessel; and those in each of the inner ones received, in like manner, the progressively accumulated cold of the next exterior pan. A more simple and convenient apparatus for freezing mercury has since been contrived by Dr. Henry, which he describes in his *Elements of Chemistry*, plate 4, fig. 42.

The materials which Mr. Walker employed were strong ni-

trous acid, sulphate of soda, and nitrate of ammonia. Other substances have also been employed for the same purpose, viz. muriatic and sulphuric acids, pure potash, nitrate of potash, muriate of ammonia, sulphate of soda, phosphate of soda, and various other salts.

It may be observed that the expense of making frigorific mixtures is trifling, because, in many cases, the salts may be recovered by evaporating the water in which they were dissolved. Mr. Walker, who was in the habit of recovering the salt, remarks that no diminution was observed in its effect, after many repeated evaporations.

But the cheapest and most efficacious salt which has been employed for the reduction of temperature is the muriate of lime, which was first used by Mr. Lowitz; and this when mixt with snow is extremely active in the production of cold. Five parts of this salt well dried, and in the state of crystals, with three parts of snow, sank the thermometer, in Mr. Walker's experiment, from 32° to -53° , which was a reduction of 85 degrees. The greatest artificial cold which has yet been observed was -91° , which is 52° lower than the point at which mercury congeals, and 123° below the freezing point of water. Mr. Lowitz directs, not only that the muriate of lime should be perfectly well dried, but that it should be in that state in which it is crystallized with the largest possible quantity of the water of crystallization, which is effected by putting the solution to cool when of the specific gravity of 1.50 or 1.53. It should be remembered that every frigorific mixture has a certain point of temperature beyond which it can never act in the production of cold, and this is the point at which the mixture itself becomes frozen.

The different materials for producing cold may be mixed in a variety of ways; but as several circumstances should be attended to, according to the nature of the articles employed, in order to afford a favourable result, I must refer the reader to Mr. Walker's publication itself for proper instructions.

Dr. Beddoes has remarked that sulphate of soda, while it retains its water of crystallization, produces, on the addition of sulphuric acid diluted with an equal weight of water, 46 degrees of cold; but when it has fallen into powder by being deprived of its water of crystallization, it produces heat rather than cold; and yet that sal ammoniac and nitre, when well dried in a crucible, produce a greater degree of cold than if they had not received this treatment. Where salts of any kind are employed, it is of consequence to have them fresh crystallized, thoroughly dried, and then finely pulverized. The mixtures should be made rapidly, and in vessels as thin as can be procured.

To this account of the various methods of producing ice by

art, may be added a new mode of effecting the same purpose, which was invented by Dr. Wollaston.

It is well known that the temperature of liquids is cooled by evaporation, but in close vessels evaporation is limited by the great bulk into which the vapour expands. Dr. Wollaston, in a paper in the Philosophical Transactions, describes an ingenious contrivance of his, to which he has given the name of CRYOPHORUS, by means of which water may be frozen in close vessels by its evaporation, with great facility.

“ The instrument which he employs is a glass tube, having an internal diameter of about one-eighth of an inch, each extremity blown into a ball, and the tube bent at right angles about half an inch from each ball. One of the balls is filled not quite half full of water. This liquid is boiled for some time to expel the air, and the capillary tube at the extremity of the other ball is then sealed hermetically. If the empty ball of this instrument be plunged into a mixture of snow and salt, the vapour within it is condensed so fast, that the water in the other ball freezes. *Ann. Phil.* vol. ii. page 230.

I cannot, however, close this part of my subject, without adverting to another philosophical expedient for the reduction of temperature, especially as it is one which has been productive of the most important and beneficial consequences. The discovery to which I refer is connected with the invention of the Miner's Safety Lamp, which has already been alluded to at the close of the first Essay, but which requires to be more particularly explained, now we are enumerating the various ways which have been resorted to for reducing the temperature of bodies by artificial means.

In the history of mining, nothing has perplexed the proprietors of our collieries, or annoyed the workmen, so much as the fire-damp; and yet many thousand men who had no other way of maintaining their families, were constantly obliged to submit to work in situations of the most imminent danger. It was usual for these poor men to creep with a lighted candle in their hands, inch by inch, as it were, along the galleries of a mine suspected to contain what they call foul air, in order to ascertain its presence, and guard themselves against its dreadful effects. But notwithstanding all their caution, explosions frequently occurred, and the consequences were often of the most melancholy kind. The miners, with the horses and machinery, were sometimes thrown through the shaft into the air, and those individuals who might happen to escape the violence of the concussion, were often gradually suffocated in being obliged to breathe the carbonic acid gas and azotic gas which always remains in the mine

after such explosions. Great numbers of men and boys are sometimes killed on such occasions; and not long ago no less than ninety-six persons who were working in the *Felling* colliery were in an instant destroyed by a similar accident.

These dreadful catastrophes kept the proprietors of our coal mines, and the families of the workmen, in a state of perpetual alarm, and little if any hope was entertained of an effectual remedy being discovered, until the subject engaged the attention of Sir H. Davy, who undertook to investigate the nature and chemical properties of the fire-damp, for the purpose of endeavouring to arrest its action, and prevent the ravages which it occasioned.

In the month of August 1815, Sir H. Davy first turned his attention to the subject, and knowing how desirable it was to find some substitute for the naked candles with which the men had been in the habit of working, he first tried Kunkel's, Canton's, and Baldwin's phosphorus, and likewise the electrical light in close glass vessels, but without success. He then constructed a lamp with two valves, so contrived that the valves closed whenever the lamp was carried into an atmosphere contaminated with fire-damp; but it was found that this lamp could not be used in explosive atmospheres.

Having been disappointed in these attempts, he then undertook "a minute chemical examination of the substance with which he had to contend (the fire-damp), and these investigations led him to the discovery of the principles by which explosion and flame may be arrested and regulated; and by means of which the miner is not only able to subdue and controul, but likewise to render useful, his most dangerous enemy."

During these experiments, he found that the fire-damp is light-carburetted hydrogen, or hydrogen gas holding carbon in solution; that it will not explode unless mixed with a portion of atmospheric air; that it explodes with most vehemence when mixed with seven or eight times its volume of air; that it retains its explosive power when mixed in the proportions of only one of gas to fourteen of air; and that when the atmospheric air is in greater quantity, the light of a taper merely becomes enlarged when brought within it, and that this effect is perceptible in a mixture of even thirty parts of air to one of gas. He found also, that the fire-damp is much less combustible than other inflammable gases; that it is not exploded by red-hot charcoal or red-hot iron, though iron at a white heat will explode it; and that "on mixing one part of carbonic acid with seven parts of an explosive mixture of fire-damp, or one part of azote with six parts, their powers of exploding were destroyed."

In the prosecution of these inquiries he found that it was dif-

ficult to explode the mixture of air and fire-damp in small tubes; and that in tubes of only one-seventh of an inch in diameter, and open to the atmosphere, it could not be inflamed, and especially if the tubes were metallic.

“In reasoning upon these various phenomena it occurred to him, as a *considerable* heat was required for the inflammation of the fire-damp, and as it produced, in burning, comparatively a *small degree* of heat, that the effect of carbonic acid and azote, and of the surfaces of small tubes, in preventing its explosion, *depended upon their cooling powers*,—upon their lowering the temperature of the exploding mixture so much that it was no longer sufficient for its continuous inflammation.”

“This idea led to an immediate result:—the possibility of constructing a lamp, in which the cooling powers of the azote and carbonic acid formed by combustion, or the cooling powers of the apertures through which the air entered or made its exit, should prevent the communication of explosion.”

“I made,” says Sir H. Davy, “several attempts to construct safety-lamps which should give light in all explosive mixtures of fire-damp; and after complicated combinations, I at length arrived at one evidently the most simple,—that of surrounding the light entirely by wire gauze, and making the same tissue feed the flame with air and also emit light.”

“In plunging a light,” continues he, “surrounded by a cylinder of fine wire gauze into an explosive mixture, I saw the whole cylinder become quietly and gradually filled with flame; the upper part of it soon appeared red-hot, yet *no explosion* was produced.”

“It was easy at once to see, that by increasing the cooling surface in the top, or in any other part of the lamp, the heat acquired by it might be diminished to any extent; and I immediately made a number of experiments to perfect this invention, which was evidently the one to be adopted, as it excluded the necessity of using glass or any fusible or brittle substance in the lamp, and not only deprived the fire-damp of its explosive powers, but rendered the inflammable gas itself an useful light.”

Omitting the detail of other experiments, it was found that iron wire gauze, composed of wires from one-fortieth to one-sixtieth of an inch in diameter, and containing twenty-eight wires or seven hundred and eighty-four apertures to the inch, was safe under all circumstances; and this material Sir H. Davy was therefore induced to adopt for the construction of lamps for coal-mines.

In the month of January 1816, these lamps were introduced at some of the large mines in the North of England; and they have been in use, with some few alterations and improvements, ever

since; the utmost confidence being now placed in them by the workmen themselves, as well as by their employers.

The circumstances which render this lamp an instrument of perfect safety may be thus stated: "Flame is gaseous matter heated so highly as to be luminous, and that to a degree of temperature beyond the white heat of metals or other solid bodies. When an attempt is made to pass flame through a very fine mesh of wire gauze, the gauze cools each portion of the elastic matter that passes through it, so as to reduce its temperature below that degree at which it is luminous; and the diminution of its temperature is proportional to the smallness of the mesh, and the mass of the metallic wire." Moreover, the fine wire gauze is not only a conductor but a radiator of heat; consequently it possesses great cooling power; and when by this, or any other means, we cool a body of flame, the effect of cooling it will most certainly be to extinguish it. The wire gauze which encircles the lamp does not prevent the passage of the inflammable gas, but it prevents its emission *in a state of inflammation*; consequently nothing can pass from the interior of a lantern properly constructed, that is, at a temperature sufficiently high to inflame the explosive atmosphere of the mine. The temperature of a metallic body, even when *white-hot*, is far below that of flame; therefore, when the wire gauze of the lantern is red-hot, it will abstract heat enough from the flame of the fire-damp to extinguish it before it passes through the meshes. So, if a wire gauze sieve be held over the flame of a common lamp, it will prevent the flame from passing it, although the heated air which passes through will be hot enough to char a piece of paper held above the sieve; a phenomenon which is precisely similar to that exhibited by the wire gauze cylinder. A very simple experiment for the further illustration of the effect thus produced, has been suggested by Sir H. Davy. "Let," says he, "the smallest possible flame be made by a single thread of cotton immersed in oil, and burning immediately upon the surface of the oil: it will be found to be about one-thirtieth of an inch in diameter. Let a fine iron wire of the one hundred and eightieth of an inch be made into a circle of one-tenth of an inch in diameter, and brought over the flame. Though at such a distance, if it be cold, it will instantly extinguish the flame: but if it be held above the flame, so as to be slightly heated, the flame may then be passed through it. That the effect depends entirely upon the power of the metal to abstract the heat of the flame, is shown by bringing a glass capillary ring of the *same* diameter and size over the flame: this being a much worse conductor of heat, will not extinguish it even when cold."

To pursue the history of the discovery and improvement of

the safety-lamp, it must be observed, that twelve months after its first adoption by the miners, viz. in January 1817, an important practical addition was made to it, founded entirely upon a new principle. Sir H. Davy having been told that the perfect safety which attended the use of his lamp, often induced the men to go into more explosive atmospheres than they otherwise would, and that this sometimes occasioned the lights to be extinguished, the genius of our philosopher enabled him, by means of the metal called platinum, to obviate the inconvenience in the most complete manner possible. Knowing that platinum has a small capacity for, and is a very slow conductor of heat, in which respects it is not at all analogous to any of the other metals except palladium, it occurred to him, that upon those properties of this metal he might found the improvement he was in search of. Pursuing this idea, he contrived to suspend a coil, or little cage of small platinum wire, from one-sixtieth to one-seventieth of an inch in thickness, over the flame of each lamp; the effect of which is, that the moment the light is extinguished by an increased quantity of fire-damp in the atmosphere, the coil of platinum wire becomes of an intense red heat; and this affords light enough to enable the men to find their way through the different passages to the entrance of the mine. This alone would have been an important improvement on the original safety-lamp:—but this is not all; for no sooner has the workman arrived at a part of the mine in which the atmosphere is in a state of greater purity, or where it contains less than one-fourth in volume of carburetted hydrogen gas, than the heated platinum wire of itself re-lights the lamp, and the men are enabled to return to their work without interruption, and in perfect safety.

There is another advantage attendant on the use of the platinum, viz. that the red-hot coil of platinum wire consumes the fire-damp within the lantern, and this without flame; yielding only a beautiful light by the ignition of the charcoal, which is one of its component parts. It is also to be observed, that a candle will burn in one of these lanterns made safe with metallic gauze, as well as in the open air; and that, whenever the fire-damp is so mixed with the external atmosphere, as to render it explosive, the light in the safe lantern will be extinguished, and warning will thus be given to the miners to withdraw from, and to ventilate that part of the mine. Another important circumstance connected with the use of the safety-lamp is, that the men can never be in any danger with respect to respiration, so long as the platinum continues ignited; for even this phenomenon ceases when the foul air forms about two-fifths of the volume of the atmosphere; and before this, it may be breathed without injury.

The action of the platinum wire has been thus described by Sir H. Davy himself: "I introduced (says he) into a wire gauze safe-lamp a small cage made of fine wire of platinum of the one-seventieth of an inch in thickness, and fixed it by means of a thick wire of platinum about two inches above the wick which was lighted. I placed the whole apparatus in a large receiver, in which, by means of a gas-holder, the air could be contaminated to any extent with coal gas. As soon as there was a slight admixture of coal gas, the platinum became ignited; the ignition continued to increase till the flame of the wick was extinguished, and till the whole cylinder became filled with flame; it then diminished. When the quantity of coal gas was increased so as to extinguish the flame, at the moment of the extinction the cage of platinum became white-hot and presented a most brilliant light. By increasing the quantity of the coal gas still further, the ignition of the platinum became less vivid. When its light was barely sensible, small quantities of air were admitted, its heat speedily increased; and by regulating the admission of coal gas and air, it again became white-hot, and soon after lighted the flame in the cylinder, which, as usual, by the addition of more atmospherical air, re-kindled the flame of the wick."

It is also remarkable that the fire-damp and the oxygen of the atmosphere will combine, when in contact with the hot wire, *without flame*; and yet produce heat enough to preserve the wire ignited, and to keep up their own combustion; and this will go on until the inflammability of the mixture is entirely destroyed. A temperature much below ignition is sufficient for producing this curious phenomenon; and if the wire be taken out of the lantern and cooled in the atmosphere till it ceases to be visibly red, when it is replaced it will again instantly become red-hot.

At first the miners were very apprehensive respecting the durability of the wire gauze; but time has increased the confidence of these men in the apparatus, which has now been in use for five or six years in the most dangerous mines in Britain, and exposed to all circumstances which the variety of explosive mixtures can occasion. And the idea of the wire gauze burning out is shown to be unfounded; for the carbonaceous matter produced from the decomposition of the oil, tends not only to prevent the oxidation of the metal, but likewise revives any oxide already formed; and this coaly matter, when the fire-damp is burning in the lamp, chokes the upper apertures of the cylinder, and gradually diminishes the heat by diminishing the quantity of the gas consumed. "I have seen," says Sir H. Davy, "wire gauze lamps in the hands of workmen, which they had used for several months, and which had been often red-hot in explosive atmospheres, and which were still perfect."

It appears moreover from Mr. Buddle's report, that the brass

collar of the wire gauze cylinders is secured to the bottoms of the lamps by locks, which can only be opened by the lamp-keeper; so that the workmen cannot either by accident or carelessness expose themselves to danger by separating the wire gauze cylinders from the bottoms of the lamps.

After finishing their day's work, the colliers bring their *Davys* (as they call them) to the lamp-keeper's cabin, who, unlocking them, takes the bottoms into his own possession and allows the colliers to take the wire gauze cylinders home for the purpose of cleaning them thoroughly. When the colliers return to their work the following morning, the lamp-keeper, having replenished the lamps with oil and cotton, lights them and screws on their tops, and then examines them with the utmost care, before he delivers them for use; but if the least injury or defect appears in the gauze, or in any other part of a lamp, it is immediately set aside to be repaired, and the person to whom it belongs is supplied with a perfect one.

The gentleman to whom the public is indebted for the above account concludes another of his reports in the following manner: "It is not necessary," says he, "that I should enlarge upon the national advantages which must result from an invention calculated to prolong our supply of mineral coal, because I think they will be obvious to every reflecting mind; but I cannot conclude without expressing my highest sentiments of admiration for those talents which have developed the properties and controlled the power of one of the most dangerous elements which human enterprize has hitherto had to encounter."

As some persons, who have no means of conversing with the workmen in mining districts, or of witnessing the action of the lamp in a coal mine, may be gratified in making the experiment for themselves, I shall relate a very simple mode by which the same effect may be produced, though in a different way, viz. By throwing a little ether into the bottom of a glass or stone jar, the vapour arising from the ether, mixing with the air, will produce what is really an explosive atmosphere, and this, when the lighted lamp is immersed in it, will burn within the wire gauze in a manner exactly similar to the real fire-damp, without inflaming the ether in the bottom of the jar.

Thus have I given the best account I am able of the discoveries that led to the invention of the Safety Lamp; which appears to me to be the most valuable and important instrument that science has presented to the arts since the discovery of the steam engine.

I have made great use of Sir H. Davy's own account of the progress of his discovery; and often in his own language¹; and

¹ See an octavo volume entitled "*On the Safety Lamp for Coal Miners; with some Researches on Flame.*" By Sir H. Davy." London, 1818.

I conceive I cannot sum up the whole better than by quoting the paragraph with which he has closed the publication alluded to. "Whatever," says he, "may be the fate of the speculative part of this inquiry, I have no anxiety as to the practical results, or as to the unimpassioned and permanent judgment of the public on the manner in which they have been developed and communicated; and no fear that an invention for the preservation of human life and the diminution of human misery will be neglected or forgotten by posterity. When the duties of men coincide with their interests, they are usually performed with alacrity; the progress of civilization ensures the existence of all real improvements; and however high the gratification of possessing the good opinion of society, there is a still more exalted pleasure in the consciousness of having laboured to be useful."

I hope it will not be thought that this detailed account of the invention of the Safety Lamp is misplaced; I had no idea it would have extended to such a length: but when it is considered that this part of my essay was expressly designed to be employed in "treating of the various expedients for increasing and diminishing temperature," I trust it will be perceived that it was impossible I could lightly pass over a discovery of such momentous interest and importance.

Having offered these remarks on a variety of expedients for the modification of heat, a few observations on some of the means of guarding against and MODIFYING the effects of COLD, may not be unacceptable to the reader.

Nature has made choice of several expedients for lessening the power of cold, and moderating the rigour of severe winters. The snow which generally covers the earth at this season is one of these, and it is very efficacious in preserving the earth at one uniform temperature, however cold may be the surrounding atmosphere. In like manner the atmosphere itself, being a bad conductor of heat, is a great preserver of the earth's temperature. Were it not for the atmosphere, the caloric inherent in the globe would soon pass off and be dissipated in unbounded space.

The temperature of the human body is uniformly preserved in the same manner. The air which is infolded within our garments prevents the animal heat from passing off, and hence it is that loose clothing is generally warmer than that which is fitted closer to the body.

There seems to be a living principle in vegetables, in the seeds of vegetables, and in fish, which enables them to resist the effects of cold, and prevents their freezing in temperatures lower than that at which water congeals. For in rivers and other great bodies of water, when the water freezes, the rapidity of the

process is moderated by the water itself giving out a large portion of caloric, during the act of freezing. This circumstance is, in a variety of instances, of incalculable benefit to the world, besides shortening the duration of winter, and lessening its severity.

Dr. Black has an experiment which decisively proves this to be a fact. "If," says he, "when the air is at 22° we expose to it a quantity of water in a tall glass, with a thermometer in it, and covered, the water will gradually cool down to 22° without freezing. Things being in this situation, if the water be shaken, part of it instantly freezes, and the temperature of the whole rises to the freezing point, so that the water acquires 10° of caloric in an instant.

Man, in different parts of the world, has availed himself of some of these principles, and applied them artificially, either to better his situation with respect to climate, or to aid him in the common operations of life.

Thus, during the winter at Hudson's Bay, the surface of the lakes and rivers is covered with ice of such great thickness, that no water can be procured without cutting through the ice with axes and wedges, which is a very laborious and tedious operation. As soon, therefore, as the surface of the water which has been laid open has acquired a thin plate of ice, the labourer heaps over it a quantity of snow, which, by being a bad conductor of heat, prevents the caloric of the water from passing upwards according to its natural tendency. It is by this expedient, that during the remainder of the winter, the inhabitants have only to remove a little of the snow, when occasion may require it, and they have water immediately. In Tibet a different expedient is adopted. "It is the practice of the husbandmen to cover the low lands in the valleys with water, immediately on the approach of winter, which incases their surface with a sheet of ice, and prevents their being stripped of the soil by the violent winds¹."

A traveller of undoubted credit informs me, that the birds killed by the shooting parties during the winter in Hudson's Bay, would be soon frozen if they were carried as is usual with sportsmen in England whilst in quest of a further supply, and that this would occasion much difficulty in removing the feathers. It is, therefore, usual to adopt the following expedient: a hole is made in the snow, and in this the birds are deposited with snow thrown over them, by which means their warmth is preserved till the party return.

In some northern regions, where there are fortified places sur-

¹ Turner's *Embassy to Thibet*, 4to, London, 1806, page 354.

rounded by moats, the inhabitants have staved casks of fish oil into the intrenchments, when they have been afraid of the approach of an enemy, that the oil, thus interposed between the surface of the water and the atmosphere, and being incongealable by cold, might protect the subjacent water from freezing, and keep the moats impassable².

The circumstance of an undisturbed body of atmospheric air defending whatever may be inclosed within it from the accession either of heat or cold, has, of late years, been taken advantage of in a variety of instances. Hence the origin of double doors and double windows, which infold sheets of air between them, and thus preserve the apartments at one uniform temperature. For, as atmospheric air is a bad conductor of heat, the doors and windows guarded in this way neither admit the heats of summer nor the cold of winter, while at the same time they prevent the escape of that genial warmth which it is so desirable to preserve in the apartments of the sick and the aged at all seasons.

In like manner certain culinary utensils are fitted up with double covers of block tin or copper, and in such utensils any fluid will boil sooner than it would in others, and will also be preserved at any particular temperature by the consumption of less fuel than would be required if they were covered only with single covers. By similar contrivances the apparatus in some manufactories is sooner heated and more easily preserved at one and the same temperament.

Leslie has shown, by direct experiment, the effect of a sheet of air in keeping metallic or other pipes warm which are designed to convey heat; and at the same time has explained how, by a like expedient, liquids might be preserved in a cool state in hot climates.

“A cylinder-canister,” says he, “of planished tin, two inches in diameter, and of equal height, filled with boiling water, took 117' to cool from 30° to 10°; but inclosed within a similar canister of four inches in diameter, it required 176' to make the same descent. Another cylindrical canister of four inches, and which took 156' to cool from 20° to 10°, required 356' when cased with a similar one of five inches³.”

I have no doubt but that ice might be transported from place to place in the midst of summer, and preserved for any length of time, if the vessel containing it were, agreeably to Mr. Leslie's proposal, placed within the innermost of a number of tin canisters, which fit one within the other, especially if the outward one were clean and polished.

² Olaus Magnus in *Historia Gentium Septentrionalium*, lib. xi. cap. 20, 21.

³ Leslie *On Heat*, 8vo, London, 1804, page 380.

On the same principle Mr. Buchanan has recommended the protecting water-pipes from freezing, by inclosing them in tin-plate tubes, leaving a space of about an inch all round the leaden pipes¹.

There is a great difference in various substances, in their power of conducting caloric, and this is shown in a remarkable manner in the manufacture of glass; for when the materials are formed into the state of perfect glass, if the manager of the fire neglect to keep the grate completely covered with coals, a stream of cold air will rise through the bars and strike upon one or more of the crucibles, which it will split or *crever*, as the workmen call it, from the top to the bottom. But if the materials be not entirely fused, so as to be converted into perfect glass, then this effect will not happen. This is a fact well known to glass-makers, and has always been deemed inexplicable. May it not however be thus explained? The materials of which glass is made have the power of conducting caloric with rapidity; consequently, when the outside of the crucible is suddenly cooled, the caloric from its inner surface can escape among the materials, and allow of its cooling in a degree equal to the cooling of the outside: on the contrary, when the glass is fully formed, it is so bad a conductor of heat that it cannot carry off that which is superabundant; therefore the crack of the crucible is the inevitable consequence.

Metals are the best conductors of heat, and hence it is that the pipes which are employed to convey heated air or steam for warming apartments, should always be metallic; and when it is desirable that the heat should be given off rapidly, these pipes should be rough, or otherwise covered with a coat of paint.

In some distilleries there is a considerable length of metallic pipes between the still-head and the worm-tub or refrigeratory: all such pipes should be painted black.

On the contrary, whenever it is an object that such pipes should preserve the heat as long as possible, as is always the case when metallic pipes are employed to convey heated air, hot water, or steam to a distance, the pipes should be conveyed under ground or otherwise highly polished, and always kept perfectly clean. A silver tea-pot on the same principle preserves the tea hotter than most others, and consequently extracts the vegetable principle more effectually. For the same reason, our planished tin covers will preserve the warmth of our provisions exactly in proportion to the height of their polish and the degree of cleanliness with which they are kept.

In some of the print-works in Lancashire, boiling-water is conveyed by copper pipes under ground from the steam-engine

¹ Buchanan *On the Economy of Heat*, 8vo, page 128.

boiler to the different workshops, for the uses of the workmen; and in some cases the heat is so well preserved, that the water is delivered in the various apartments only two or three degrees below the boiling point.

With respect to the **ECONOMY** of **FUEL**, which naturally forms a branch of this essay, so much has been professedly written upon the subject by Count Rumford, that there seems nothing of importance left for others to add. I shall therefore presume to offer very little to his observations, except a few hints which arise out of my own practice in the conduct of the manufactory in which I am personally engaged.

It is impossible, in an economical point of view, to give any general directions for the choice of coal, since this depends so much on the different localities and other circumstances; a description of the several varieties will be found in the *Essay on Carbon*. It may, however, be observed, that in manufactories where large and expensive iron boilers are employed, sulphurous coals should be avoided, as the sulphur which rises during combustion is apt to occasion a rapid decay of that part of the boiler which is exposed to the action of the fire. It produces a sulphuret of iron, which wastes away as fast as it is formed. This is more particularly the case with those cast-iron stills which are required to be red-hot, such as the pots in which the makers of prussian blue flux a mixture of animal hoofs and horns with a caustic fixed alkali.

The following table of the comparative heat of different kinds of fuel was drawn up by Mons. Lavoisier. Equal quantities of heat were produced by the combustion of the following quantities of the combustibles annexed.

	Pounds.	Measure.		Pounds.	Measure.
Cokes	403	17	Charcoal	600	40
Pitcoal	600	10	Oak wood	1089	33

In this experiment the cokes required $12\frac{1}{2}$ hours for their combustion, the coal 20 hours, the charcoal 5, the oak 4—4. An estimate has also been made of the relative quantities of heat produced from similar materials by Count Rumford, but I must refer the reader to his work for particulars².

M. Wiegleb has stated it as his opinion, that in the choice of wood-fuel, the beech and hornbeam are to be preferred; next the oak, and then any other woods of great solidity. Next to these, the alder, aspen, birch, fir, ash, and the lime. The former excite a greater heat, and burn longer; the latter exhibit more flame, and leave but little residuum.

Loyssel has shown that it is improvident to burn different spe-

² Rumford's *Essays*, vol. ii. pages 75, &c., also pages 134—137.

cies of wood together, and that it is absolutely important in many operations to sort the wood, and never to use more than one kind at a time in those works which require a lively clear fire and a pure flame¹.

Charcoal is fitter for small chemical operations, as it is more easily managed: that which is made of the more solid woods is to be preferred.

Refuse tan, made up into cakes, is also very fit for firing, where a gentle and continued heat is advantageous.

In some places turf is used with advantage. Formerly it was much employed in some of our West Indian islands; but since hands have been scarce in consequence of the discontinuance of the slave trade, the planters cannot spare any of their men to cast turf, and are now obliged to take pitcoal from England. There is a great difference, however, in its internal quality: the heavy bituminous kind called *peat*² is the best; but some care is required in drying it properly to prevent its entering into spontaneous combustion.

Mr. Mushet, of the Clyde iron works, gives the following calculation of the expense of getting peat in Scotland. A man, he says, will with ease cast 4,000 of an ordinary size in a day. For this quantity are required two carriers, and one person to pile it to dry. The peat when thoroughly dried will weigh nine pounds each; the product, therefore, will be 12,000 pounds, or upwards of five tons. The expense of this is:—Man's wages per day, 2s. 6d. Two women, at 1s. each, 2s. Girl to pile it, 6d.—making 5s. or one shilling per ton.

It has been found that four tons of dried peat will make something more than one ton of peat-char, which will produce a much stronger fire than coals or cokes.

Dr. Plot, after describing the method of cutting turf in Staffordshire, says, “the large ones in good weather will dry on one side in eight, on the other in four or five days at most. When dried, if they intend them for fuel in winter, they pile them up round in the manner of a hay-rick, ten or twelve feet high, and let them stand all summer; but if they are designed for manuring their land, they heap them up a good quantity together on the ground and set fire to them, which they will take of themselves if they are dry³.

¹ *Essai sur l'Art de la Verrerie*, page 67.

² This article has for ages been used as fuel by the people of the north of Europe; but the learned Torfeus says that its use was first made known to the inhabitants of the Orkney and Shetland islands, by one Einar, a Norwegian, who from that circumstance was named Torf Einar. Jameson's *Mineralogy of the Scottish Isles*, quarto, 1800, vol. ii. page 121.

³ Plot's *Staffordshire*, chap. iii. § 14.

A very economical kind of fuel is charred turf, but it has a very disagreeable smell during its combustion, which is an objection to its use in open fire-places, and there is some nicety required in managing the process of preparing it, which I believe nothing but practice can teach. M. Sage, who has published a paper on this subject in the *Memoirs of the Academy of Sciences at Paris*, entitled "An Inquiry into the comparative Intensity of the Heat produced by the Combustion of Charcoal and charred Turf," asserts that the heat produced from the latter is nearly in the proportion of three to one⁴.

The management is, however, generally of greater consequence than the choice of fuel. The kind of fuel which is most suitable for any particular operation, is soon discovered, but how to employ it so as to produce the greatest quantum of heat by its means is not quite so obvious.

Count Rumford has stated that, in general, not less than seven-eighths of the heat generated, or which with proper management might be generated, from the fuel actually consumed, is carried up into the atmosphere with the smoke, and totally lost. How important then is it that every proprietor of a manufactory should investigate the causes of this loss, and endeavour to remove them!

In the year 1686 Dalesmius contrived a furnace at Paris on a very simple construction, for economizing fuel by burning the smoke. Since that period we have had many contrivances for the same purpose, possessing different degrees of merit, and an account of most of them may be seen in the periodical journals of the day.

Where boilers are set in brick-work over closed fire-places, the most common defect is that of having the fire-places too large. This often arises from the obstinacy of an unskilful brick-layer. It is a great want of economy to employ inferior workmen to erect any kind of fire-work. Whatever may be the expense, I have always found an advantage in having furnaces well built in the first instance. The consequence of having the fire-place too large is, that the bars cannot be entirely covered with fuel, and the cold air rushing from the ash-pit, between the uncovered bars, actually counteracts the effect of a great part of the burning fuel. In setting stills or boilers, it should be a general rule to have the fire-places no larger than is absolutely necessary for containing as much fuel as will be required to produce the intended purpose.

The fire-place should not only be small, but it should be constructed so that the whole of the bottom of the boiler be exposed

⁴ An abstract of this paper may be seen in *The Repertory of Arts*; vol. v. page 419.

to the action of the burning fuel. This is very effectually accomplished in some steam-engine boilers. These are of an oblong form, and they have a flue of from eighteen to thirty inches diameter running from end to end through the middle of them. The fire therefore first plays against the bottom of the boiler, and then passes through the midst of the water before it reaches the chimney. Might not this principle be applied in various other ways with advantage? It is important that the whole of the flame and heated air do actually impinge upon the bottom before they reach the sides to pass from them to the chimney; for the heat which is applied at the bottom of a boiler will be infinitely more effective than the same portion of heat when applied to its sides. It is on this account that some large stills and other vessels of copper are made with the bottom to project inwards, presenting a concave instead of a convex surface to the action of the fire.

These considerations explain why there is so great a waste of fuel whenever pots or other vessels are heated over an open fire-place; for in this case, the heat only skims over the bottom, and passes off immediately into the surrounding atmosphere.

The doors of closed fire-places also are generally as improper as the fire-places themselves. They are usually made extremely thin, and the frames very light; which not only occasions them soon to wear out, but is the cause of their warping and twisting, and consequently they never shut close afterwards. These doors are likewise made to fall into a rabbet, and are fitted up with latches, both of which are inconvenient, and indeed useless.

Having had many years experience in fitting up furnaces, I am decidedly of opinion that where cast-iron doors are employed, an opening of ten inches should have a door not less than three quarters of an inch thick; and larger fire-places should have thicker doors in proportion. These should be fitted up with strong wrought-iron hinges, such as will allow the doors to fall flat against the frames; and instead of moveable latches, each door should have a large projecting knob firmly riveted into it.

I have found it advantageous to have the straps of the hinges thick, and of such a length as to extend entirely across the door; for when these are well riveted to the door, they prevent the latter from warping, however intense may be the fire.

The cast-iron frames ought to be as thick at least as the doors; and they should be two or three inches broad, to enable them to stand steadily against the walls of the furnace. In setting the frames, they should be fixed inclining a little towards the fire-place: this gives the doors a tendency to keep shut, and renders latches useless. Bars of wrought-iron, well fastened, should

also go, one from each corner, in a spreading direction, not less than eighteen inches or two feet into the solid mass of brick-work on which the boiler is to stand.

There is a benefit arising from having these straps long and substantial, which may not at first be apparent. They prevent the frame from receding from the brick-work, the consequence of which would be that air would pass into the fire-place between the frame and the masonry, and thus impair the draught of the furnace.

It is also of importance in every close fire-place, to have a door to the ash-pit; one that shuts easily and fits close to the frame on which it hangs; for without this it is impossible ever to regulate a fire so as to reap every advantage from its effects.

Having experienced the benefit of ash-pit doors, I have for several years been in the practice of having my fire-places fitted up with double doors and frames; that is, I have a strong iron frame cast, with two openings; to one a door is hung for the fire-place, and to the lower opening I adapt another for the ash-pit. The peculiar advantage of this is, that a double frame of this sort is more easily fixed, and can be attached more firmly to the brick-work, than it would be possible to fix two frames, one immediately above the other.

These doors and frames are expensive at first, because they are weighty; but in the end they will be found to be more economical than any ready-made sale-doors that can be found.

Besides, since I have had these doors to the ash-pits I have dispensed with the registers in the chimneys; for, I find that by a proper attention to the opening and shutting of the ash-pit door, I can admit any portion of atmospheric air into the fire-place, and thus have a complete command of the temperature and its application.

For some time I had registers in the chimneys, as well as doors to the ash-pits; but finding that both were more than servants would attend to, I have now discarded the former altogether, and perceive that every effect that can be desired may be produced by the ash-pit doors alone.

However deep the ash-pits may be, it is always advisable to have doors to them. Some scientific men in the metropolis have had doors of three feet in height to the ash-pits of their brewing coppers, and have found them very economical.

I have sometimes had moveable registers in the centre of the ash-pit doors; but these are too troublesome to be managed by ordinary servants; and a common plain ash-pit door, when properly hung, may be readily opened an inch, two inches or more, or entirely shut, according to the choice of the laboratory-man employed.

In reverberatory furnaces for the decomposition of neutral salts and the manufacture of alkalies, ash-pit doors are of no use, as it is never necessary to check the fire suddenly, as in other operations. On the contrary, I have found it advantageous to have the ash-pits as deep and the chimneys as high as possible, in order to occasion a strong and uninterrupted draught.

No chimney should be less than thirty feet high; and for large fire-places, or where more than one flue goes into a chimney, it ought to be much higher, and larger in proportion.

At Paddington water-works the chimney is 120 feet from the plinth to the summit, and the chimney of the spinning factory of Messrs. Broom, Sons, and Home, at Kidderminster, is of the enormous height of 220 feet; and being quite round and beautifully constructed, it is a remarkable object for a great distance from the surrounding neighbourhood.

I cannot suffer this opportunity to pass without remarking that the proprietors of reverberatory furnaces should contrive to continue their processes night and day; or, if that be impracticable, they should rake up the fire and stop the passage to the chimney so as to prevent the furnace from cooling during the night. Furnaces thus worked will last six or seven times as long as those do which frequently stand idle. The contraction of the materials during the time of cooling, and the subsequent expansion, wear them out rapidly.

Where the heat is so intense as it is in these furnaces, doors and frames of the common make, or such as have been just described, would be quite improper, and even wasteful, for they would be constantly red-hot: hence they would not only soon wear away, but being in this state of incandescence they would carry off a large portion of the heat, which ought to be employed in reducing the materials within the furnace.

For large reverberatory furnaces, steam-engine boilers, and other great concerns, I have sometimes seen very wide wrought-iron doors lined on the inside with a plate of cast-iron well riveted to the door. By forming these hollow, that is, if they were put together so as to inclose a thick sheet of atmospheric air, the door would become a non-conductor of heat, and would be very suitable for such apparatus.

Having experienced the inconvenience of common doors and frames, I had recourse to a contrivance of hanging a thin sheet of wrought-iron before the fire-place, which proved to be a great amendment; and after this I had a door made with fire-bricks, the joints of which were secured with loam, and held in their places by four flat plates of iron screwed together at the corners. This massy door was moved upwards or let down before the fire-

place by means of a weight which exactly balanced it, and was attached to a chain passing over a pulley.

This was an improvement upon the former; but both had their inconveniences, and these inconveniences led to the adoption of a small iron hopper fixed horizontally in the brick-work, properly let into the wall to defend it from the fire, and stopped by a thick piece of iron, cast exactly to fit it. This I found to be a most complete way of closing a fire-place, as no air can possibly get admittance but through the ash-pit, this being the only way by which it ought ever to pass. I made use of this kind of hopper twenty years ago, and have never seen any reason to alter my opinion of it. I was indebted to a work of Mr. Dossie, "The Elaboratory laid open," for the idea.

There is, however, an inconvenience attending these square stoppers of iron, viz. If the wall of the fire-place be not very thick, and the hopper fixed at the very outside of the brick-work; whenever the fire becomes intense, the stopper is apt to expand by the heat, and get so firmly fixed within the hopper as sometimes to be attended with much trouble. I have, however, occasionally employed these kind of hoppers for closed fire-places of the very smallest size, and have then been much satisfied with them. In such cases the heat not being so intense, this inconvenience does not happen.

Reflecting on the objection just referred to, it occurred to me that a hopper might be so fixed as to be stopped with small coal instead of the usual door, and that in this way the difficulty might be avoided. I therefore made such an alteration in the construction of the last reverberatory furnace which I had occasion to erect, as enabled me entirely to discard the use of any metallic door or stopper whatever.

In this furnace the hopper which I employed was five inches square in the clear, and this was fixed upon a broad plate of iron built in the brick-work, and projecting eight inches beyond the face of the wall. The design of this was merely to be a support for the small coal which was to fill the hopper, and be piled against it, as a succedaneum for the iron stopper above mentioned. Since this was first written I have found that glass-makers stop up the mouths of their ovens with small coal, on the principle of its being a non-conductor of heat, and that this contrivance answers their purpose completely. It appears also that iron-founders stop up the mouths of their air-furnaces in the same manner.

The small of pit-coal, being a non-conductor of heat, proved to be a mode of stopping the entrance of a furnace as perfect as probably will ever be devised: for, if a furnace draw well, the coal which fills the hopper will not become ignited at all, except

that part of it which is nearest the burning fuel; and when the hopper is properly stopped, one cannot discover how any of the heat of the furnace can possibly escape by means of the door-way.

When it becomes necessary to replenish the fire, all that the workman has to do, is to loosen the coal within the hopper, to push the whole of it into the fire-place with a shovel which should be made on purpose to fit it, then to throw in as much fresh fuel as he judges to be sufficient, and again to stop up with small coal as before. It must be observed, that the hopper should be fixed several inches above the level of the fire-bars, that whatever fuel is put through may fall into the fire-place without any difficulty.

It should be recollected, however, that whatever perfection there may be in the mode of stopping the entrance into a furnace, this will be no cure for a large fire-place; for if a fire-place be larger than it ought to be, or so constructed that the hopper does not command every part of it, a continual current of cold atmospheric air will rush in between those bars which are not covered with fuel, and carry much of that heat into the channel of the chimney which ought to be spent within the furnace.

This is the chief circumstance which renders a hopper fire-place so much better than those with a door and frame; for where there is a hopper there can be no occasion for any door and frame; and the *four* sides of the furnace may be built exactly alike and all brought up sloping with masonry. Such a furnace will hold much more fuel than one that has only *three* sides of brick-work; and consequently the area for the bars may be much diminished. Indeed, one of the most important alterations of late years in the building of inclosed fire-places, is that of reducing their length to one half of the former dimensions, and adding something in lieu of the length to the width. The advantages which arise from this alteration will easily be perceived. It was no uncommon thing formerly to build the fire-place of a furnace four feet long.

Besides, if the four sides of any furnace be sloped very considerably, so that its upper diameter be twice the diameter at the bars, there will never be any danger of such a furnace having a false draught through the bars; because whatever fuel is thrown in through the hopper, will fall on all sides towards the middle of the furnace, and form a uniform covering to the grating.

I have found it convenient to have the hopper on one side of a furnace and the ash-pit on another, or at the end of the furnace: by this arrangement the assistant can supply his fire without being annoyed by the heat of the ash-pit, which is considerable in large furnaces.

It has lately been found advantageous to have fire-bars much narrower than formerly. By this alteration a fire burns more

regularly, being more equally supplied with atmospheric air than it could be in fire-places with bars three inches wide. Half that substance is sufficient for any fire-place.

Respecting the width between the bars, the space which I have found to be the best, is half an inch, and this is sufficient for a fire-place of any dimensions. By casting the bars with a shoulder at each end, exactly a quarter of an inch thick, it gives the proper opening.

Such furnaces as are designed for producing a great heat, should be furnished with loose bars of a considerable size, resting upon two or three strong bearing-bars; for all grates, or sets of bars cast together and united in one frame, will warp and twist, and are with great difficulty cleared of the scoriæ or clinkers. Joggle-bars, as they are called, or such as fall into distinct and separate notches, are also very inconvenient. It is seldom advisable to buy ready-made fire-bars, but it is more profitable for the proprietor of a manufactory to have a pattern in wood, for each kind of furnace, made to his own mind, and to have all the bars of that size cast by it, taking care to have a knob at each end, to keep the bars at a proper distance from each other.

If such bars be fixed upon strong and plain bearers, they will have room to expand by the heat without bending; may easily be moved to the right or the left, to loosen the scoriæ; and may readily be drawn out of the fire-place at pleasure.

In building a large furnace I have found it convenient, when I have employed a hopper, to leave an opening of two or three inches immediately above the fire-bars, as long as the whole breadth of the fire-place; and such an opening may be easily made by inserting a strong bar to support the brick-work over it. Through this opening the workman can occasionally introduce a poker for stirring the fire and loosening the scoriæ, and through the same opening he can withdraw the bars for the sake of emptying the fire-place, or replace them, as he may have occasion.

When a fire-place is built after this manner, it will be convenient to have a deep ash-pit: then, if the workman wishes at any time to cool the furnace expeditiously, he can draw out the bars through the orifice above mentioned, and the whole contents of the fire-place will fall at once into the ash-pit.

At some very large steam-engines I have seen a fixed door and frame at the opposite end of the furnace to that at which they feed the fire, for the purpose of drawing out the clinkers of the coals, without incommoding the man who attends the fire; but I know from experience that the construction just described will in the end prove to be the most convenient. The aperture, as

it rises only three inches above the surface of the bars, will not injure the draught of the fire-place, because the bed of fuel which covers the bars will be always thick enough to stop up that opening completely.

I have already urged the importance of employing an ingenious and experienced bricklayer, for it will always be prudent and economical to have every furnace well built at the first: for such furnaces not only answer their respective purposes better, but they consume less fuel, and will frequently last three or four times longer than those which are built by an ordinary workman.

To effect this in the best manner, it is obvious that the materials should be of the best kind, carefully selected for the respective parts of the work, and calculated for that particular furnace which the proprietor wishes to erect.

There are, however, a few necessary instructions from which I have derived so much advantage in my own manufactory, that I should be inexcusable were I to neglect to mention them.

It is a common opinion, that if good fire-bricks be used in the interior of the fire-place and in the flues, any thing will do for the exterior, or for the solid part of the fabric. This is not strictly true, for I have found it advisable to have even the external parts composed of the best building bricks that I could procure; because close joints and compact work can only be made with such materials; and if the workman does not lay close joints, and make the whole fabric very compact, he can never be certain that the air will not find a passage into the fire-place through other channels besides the ash-pit. Besides, whenever a furnace is taken down to repair a fire-place, these bricks may be used again and again; whereas common *place-bricks* can never be taken down whole, and consequently are useless for a second erection.

Wherever an intense fire is required, bricks made with the best Stourbridge fire-clay should be used; the joints should be rubbed very close, and that part of the work should be laid, not with lime mortar but with good fire-lute.

The fire-lute which I have employed for many years, never having been able to discover a better, is made thus: Good clay two parts, sharp washed sand eight parts, horse-dung one part. These materials are to be intimately mixed, then beaten up with a little water, and afterwards the whole is to be thoroughly tempered like mortar, by treading it for a considerable time with the feet. Mr. Watt's fire-lute is a good one, but it is more expensive. Take, says he, porcelain clay from Cornwall (not pipe clay), pound it, and mix it to the consistence of thick paint, with a solution of borax, in the proportion of two ounces of borax to a pint of hot water.

In erecting furnaces which are intended to sustain a great heat,

the composition of the mortar is of the utmost importance. When I was in the habit of using stone-lime, such as is produced in several of the midland counties of England, I found the following proportions made the hardest and the best mortar.

Lime fresh burnt, and measured while in lumps, one bushel; sharp river sand, well washed, four bushels. The whole to be intimately mixed and thoroughly tempered.

For the internal parts, which are not exposed to the air, a still larger proportion of sand might, I found, be used with advantage.

The best proportions for common chalk-lime are, lime one bushel, and sharp sand two bushels; though that which is thoroughly and uniformly burnt will take three bushels of sand to one of lime.

It has long been a general complaint that the common chalk-lime contains a considerable proportion of unburnt stone, or carbonate of lime, which is a great loss, and renders it difficult to ascertain the exact measure of sand that ought to be used with it.

In consequence of this, some lime-kilns have been erected at Bow and elsewhere in the neighbourhood of London, with chimneys which rise thirty feet above the body of the kiln; and these occasion so powerful a draught that the complaint just mentioned is entirely obviated.

In the *Journal de Physique* for the year 1775, page 311, are a plan and a description of a kiln for burning lime *after* it has been once slacked and reduced to powder. The design of this is, that it may be used in mortar quite hot. It is recommended to be employed in the following proportions, and it is said that such mortar will become extremely hard and durable. Fine sand three parts; well burnt brick, ground, two; slacked lime two; lime slacked in the air, and afterwards recalcined, two.

The stone consistence which mortar acquires is owing partly to the gradual absorption of carbonic acid, and partly to the chemical combination of a portion of the water which is employed in making it. Hence, if lime reduced to powder and then recalcined, or burnt lime reduced to powder without being slacked, be added to mortar, the mortar when dry will acquire much greater hardness than it otherwise would.

For the different works at Woolwich and elsewhere, belonging to Government, all the lime which is consumed in making mortar is ground while dry to a very fine powder, and used in that state without being previously slacked. It is taken from the kiln quite hot, and ground in that state. This prevents that absorption of carbonic acid gas which would otherwise take place; and in making mortar with such lime, as much water is required as would be combined with the lime if treated in the

common way, and a much larger proportion of sand may be employed than can possibly be used even with the best lime if prepared after the old manner; and it has often been demonstrated that, provided the mortar have sufficient tenacity, it will form a harder cement in proportion to the quantity of sand employed.

The mortar of the ancients contained more sand than is generally used at present, and the extreme solidity of all the ancient buildings has often been noticed. Pliny and Vitruvius¹ have informed us what were the proportions of lime and sand used in their time, and that it was customary to burn the lime close to the spot where the buildings were erected, that the workmen might have it immediately from the kiln.

“The greatest part of the wall built by King Athelstan in the neighbourhood of Exeter is still remaining. It consists of small unhewn stones as they were dug from the quarry, the interstices filled up with hot lime and rough sand, and faced with ashler work of hewn stone, and the whole strengthened by strong buttresses. The mortar used in this work is from length of time become so hard and durable, that, on attempting to pull down any part of it, the stones are sooner broken than separated one from the other².” I am inclined to think that the lime made from *chalk* is always the strongest in proportion to the quantity of iron contained in it. I have found that the whiter the chalk the weaker will be the lime that is made from it; whereas that which is made from the dark gray chalk approaches most to the nature of stone lime, and is less perishable by water. The lime made at Dorking in Surrey is of this latter kind, and is in great demand for various purposes of building under water. Other instances in corroboration of the idea now suggested might be easily adduced: thus the chalk of Portsdown-hill in the county of Hants is soft and white, and the lime made from it is used only for common building purposes; whilst the chalk of Butsa-hill, fifty-eight miles from London, and likewise in Hampshire, is a hard gray chalk, making a description of lime which is employed for the foundation works under water of the dock-yard and fortifications at Portsmouth, it being equal or superior to the Dorking lime.

For some purposes, Stourbridge clay alone is very suitable for imbedding fire-bricks, as it burns into a substance similar to the bricks themselves, and the whole furnace becomes like one solid uniform mass. The Stourbridge clay is of a very peculiar kind; it lies at a great depth in the earth, under the bed of coal, and is known to the workmen by the name of *clunch*. It is a gray

¹ Plin. Lib. xxxvi. c. 23.—Vitruv. *Architectura*, lib. ii. c. 5.

² Jenkins's *History of the City of Exeter*, 8vo. 1806, page 17.

clay, of a sandy nature, and better adapted for making large crucibles and fire-brick than perhaps any in Europe.

It is not generally known, but there are some brick-makers at Stourbridge, proprietors of the clay-pits there, who will make bricks of any form or of any dimensions that may be desired. Some friends of mine have had an entire fire-place made with that sort of clay, agreeably to patterns sent for the purpose; and it was so contrived, that though the bricks differed in form and size, every piece had its appropriate place, and fitted the adjoining one with the greatest nicety.

For some particular purposes it will be worth while to go to this expense; for, when the several parts are put together with a thin mixture of Stourbridge clay, sharp sand, and water, the first fire that is lighted within the furnace, will burn the whole into one entire and compact body.

In putting up the large stills used in the distillation of nitrous and muriatic acids, I have been accustomed to have an abundance of old iron hoops laid within the solid brick-work, some on every course; with the view of holding it together and preventing a strong fire from cracking it, or forcing it outwards;—but I am now of opinion that these are not of much use, excepting in chimneys and in the walls which form the flues, and where the brick-work is necessarily very thin; for even where a great number of hoops have been laid in, the work has sometimes cracked, and produced a false draught in the fire-place.

A better expedient, and one which I have lately adopted with great success, is that of laying four flat iron bars in the brick-work of each still, one on each side of the fabric, and at the height where the fire has most force. I have these bars three-eighths of an inch thick, and two inches broad, and of a length sufficient to extend the whole length or breadth of the mass of brick-work in which they are to be imbedded.

These bars are made by the smith to fit the places where they are to lie, and are bent at each end so as to clip the masonry and prevent its moving: but before they are bent there is a slit of about two inches made in the end of each, which enables the smith to divide so much of the bar and to turn one half up and the other half down, by which contrivance it binds two courses of brick-work instead of one. I have been thus minute in describing these binding bars that the method of making them cannot be mistaken.

The irons being thus prepared, and the work brought up to the proper height to receive them, the bricklayer places one on one side of the furnace and another on its opposite side, and then raises another course of brick-work all round the whole area. Two of the irons being thus built in, the two others are laid in

the same manner on the other two sides of the furnace, and built in as before. By this arrangement the whole is secured in a very complete manner, and I see no reason to expect that any thing will give way till either the stills or the fire-places are entirely worn out.

These expedients are all designed for the purpose of making the work durable, and preventing a current of atmospheric air setting in towards the fire-place in any direction otherwise than through the ash-pit: but for the economy of fuel, it is of equal importance that the bricklayer should be careful in the construction of the chimney, on which the goodness of every furnace very much depends.

In determining the form, the size, and the height of a chimney, an experienced workman will have no difficulty; but it appears to me that a proper attention is not always paid to the thickness of the walls, or to the materials of which they are built.

No outer wall of a chimney, however small it may be, should be less than nine inches thick, but it would be better if they were fourteen or eighteen inches in thickness; and such materials should always be chosen as are the worst conductors of heat, provided they are sufficiently compact, and have no crevices for the admission of atmospheric air.

Speaking of materials which are slow conductors of heat, reminds me that some improvement might be made in the construction of our large boilers and evaporating pans, as to their power of conducting heat. What could possibly be worse contrived for preserving the heat than the large iron pans of the soap-boiler, which generally stand three or four feet out of the ground without any casing whatever? Our soap-makers formerly boiled in wood. The French manufacturer boils in brick.

But to return to the construction of chimneys: it is not only requisite that a chimney should admit no atmospheric air through its sides, but it is also desirable that the sides of the chimney should not cool the smoke and heated air within it; for, the higher the temperature can be kept in the interior, the better will be the draught.

Whatever may be the situation of a chimney, it is always best to have it stand independent of the boiler, still, or furnace to which it belongs. It is best to build the chimney first, and when that is finished, then to erect the apparatus round it, as may be most convenient.

Some chimneys are placed at the back of a furnace, others over the door: some boilers are set immediately over the centre of the fire-place, others at a considerable distance from it: in some cases the still or the boiler is suspended over the furnace, so that the bottom is entirely exposed to the action of the fire,

while in other instances the still is supported by brick-work, and only partially exposed to the fire: one is heated only by the flame and hot air which impinge against the bottom; others have split draughts and worm flues of different kinds; and each of these modes may be applied with advantage to some particular purposes. But, as a skilful workman will never be at a loss to decide these points, I hasten to offer a few remarks on the management of the fuel, previous to the consideration of the necessity of an attention to temperature in our manufacturing processes; which, although the last, is certainly not the least important branch of this interesting subject.

If a chimney throws out a large quantity of smoke, it is impossible there can be a proper economy of the fuel; for the smoke is occasioned by particles of the coal which ought to have been detained in the fire-place, and there consumed in the production of heat¹.

This loss is chiefly occasioned by too much coal being cast into the fire-place at once, which prevents any of it from being properly ignited; whereas, if a small portion were always thrown in at a time, and this suffered to become thoroughly inflamed, or half burnt out, before more were added, the combustion would then proceed regularly, more heat would be produced, and not half the coals would be used which are now consumed. I have found it advisable not to disturb the fire burning in a closed fire-place, more than necessary. Coals should be put so as they may lie light upon the grate. These are points of considerable importance in every manufactory where many coals are burnt; but it is very difficult to induce ordinary servants to attend to it; because, when the fire-door is opened, there is less trouble in putting on two or three shovels full of coal at once, than in furnishing half a shovel full at a time, and that very frequently.

The effect of heaping an unnecessary quantity of coals upon a grate in a closed fire-place is very mischievous and detrimental. The great mass, instead of entering properly into combustion, only moulders away, or is carried in the state of smoke through the channel of the chimney into the atmosphere; and the heat which is produced by the coals, instead of rising up to the boiler, and doing its proper office there, is forced through the bars into the ash-pit, and entirely lost.

A workman who would attend to these particulars would save to his employer what would be equal to his own wages, in fuel; the work would be better done, and the effect produced with

¹ What Dr. Black has said on this subject is worth the perusal of manufacturers; it may be seen in his *Lectures*, 4to. vol. i. page 312—316.

more certainty. Besides, when the fuel is burnt to such a point as to have become a kind of charcoal, and no more smoke is given off, instead of heaping fresh coals upon such fuel, the ash-pit door should for a time be shut, to prevent the access of cold air; and the fuel, in this high state of ignition, should be left undisturbed, in order that it may have its proper influence on the matter submitted to its action. Practice alone can teach how long a fire should remain in this state: but it is of consequence to manage it thus; for whenever, after this treatment, a proper quantity of fresh fuel is added, this fresh fuel will sooner get into full combustion, and the whole of it will be effective.

I am desirous, however, of observing, that all these remarks are designed to apply only to such furnaces as are constructed in the usual manner; being aware that there are patents for erecting fire-places to consume their own smoke, in which the proprietors direct large fires to be made which will not require to be replenished with coals for many hours. Some of these expedients have already been referred to at page 77 of this work.

I pass over many other important particulars respecting the management and economy of fuel in closed fire-places, because they have already been well considered and explained in excellent detail by Count Rumford, whose *Essays* may be studied with advantage by all those who are desirous of investigating this important subject¹.

Much might be done in the way of economy, by the employment of the waste heat which is now lost in the generality of manufactories, and which the proprietors, by a little reflection, might contrive to put to a good account.

In large buildings where it is necessary to have iron pillars to support the floors, how easy would it be, as these pillars are usually cast hollow, to convey heated air, or waste steam, from an engine-boiler through them, and thus warm extensive premises at no expense! There is a perfection peculiar to cast-iron pillars, that they may be made ornamental at a cheap rate; and hollow pillars for supporting a roof or floor, cost much less than those which are cast solid, and are still of sufficient strength.

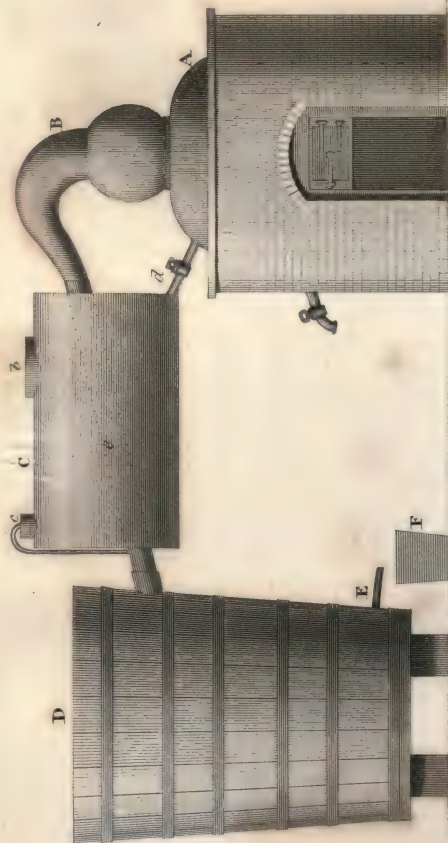
A gentleman whom I know in the neighbourhood of Manchester erected a cotton-mill, several stories high, on this principle. The floors consist of a number of small brick arches, the abutments of which are supported by hollow pillars of cast iron, and these pillars are heated with steam, or kept cool, as he sees occasion. By this construction he also saves insurance, as there

¹ Rumford's *Essays*, vol. ii. Essay 6; and vol. iii. Essays 10, 11 and 14.



ECONOMICAL STILL.

Plate 3.



- A. The Still...
- B. Still Head...
- C. Condenser...
- D. Worm Tub...
- E. The Worms...

- a. Man hole...
- c. Safety valves...
- d. Stop Cock...
- e. Purifier pipe...
- F. Receivers...

Designed by T. Davis for Parkes's Chemical Engine.

is nothing combustible employed throughout the building. After his example, many factories have lately been erected on a similar plan in various parts of the kingdom.

I have often noticed the vast loss of heat arising from the exposed state of most of the steam-engine boilers. There would surely be an advantage in building a wall round them, and covering them from the action of the weather. Thus there would be a hot room attached to every steam-boiler, which might be applied to many useful purposes.

In like manner, to those manufacturers who have occasion for large quantities of coke, if they have coal in their neighbourhood that will coke, how advantageous would it be to put up a proper oven or two for the purpose, and apply the spare heat for burning lime, heating stoves, &c. ! The heat that is usually lost is very considerable, and it is so intense that it might be made sufficient for almost any purpose.

In most cases of distillation, the liquid which comes over is run through a refrigerating metallic worm immersed in a vast quantity of water. The design of this is to convert the gaseous product into a fluid nearly as cold as the surrounding atmosphere, and which without this would be mostly lost in steam. Why might not the worm in many cases be passed through an intermediate vessel surrounded by the wort or other liquid which is intended to be distilled, and which by this means could be heated to a certain point in readiness for the still, and at no additional expense? Plate, No. 2.

In some of the West India Islands this principle is already acted upon. A worm is made to pass through the sugar-wash, and this heats it ready for the still, and thus enables the planter to draw more rum in a given time. It has been thought, however, that the principle might be applied with more effect, if the heated air and smoke from the fire-place were made to pass through the wash : and several sets of apparatus of this kind have been prepared in London for some houses in Jamaica. A drawing of one of these I have procured, and have had it engraved to accompany these Essays. Plates, fig. 8.

A great saving of fuel is also effected by the introduction of the dome and back copper. This vessel, which is used by some brewers for boiling their wort, is constructed like a common copper, except in the cover, which is made like a very broad-brimmed hat, turned up very high all round the edge.

When the wort within the copper boils, the attendant turns a cock and fills this broad gutter in the cover with cold liquor. The consequence of this is, that the cover being filled with many gallons of cold wort, it condenses the steam as soon as it is formed, and becomes itself heated to 170° or 180° . When the

liquor acquires this heat, it is let off into the copper below, and the cover is refilled with cold liquor.

For safety, the crown of this cover is furnished with a weighted valve, from whence the steam may escape whenever the fire is greater than it ought to be. By having the wort thus covered all the time it is boiling, the fine aroma or peculiar and grateful flavour of the hop is entirely preserved; whereas in a common open copper it passes off with the steam. The saving of coals is also considerable.

These desultory observations on the economy of fuel having been extended much further than was at first designed, I must be more concise than I otherwise would in describing those cases which have been selected as instances of the importance of paying an attention to *temperature* in the conduct of manufacturing processes, and with these I shall conclude this Essay.

There is no complaint so common among workmen, as that of processes sometimes failing which have usually succeeded, and this without any apparent cause. Scarcely do I recollect an instance of such failure, without having had reason to suspect that it arose in some measure from a want of attention to the temperature at which the process was conducted.

The distiller of ardent spirits knows how important it is to regulate the temperature of the refrigeratory, and that, if it rise above a certain degree, a portion of the distilled spirit will be dissipated in the atmosphere and lost: the glass-maker is aware that the goodness of his glass entirely depends on the care with which he reduces the temperature in the process of annealing: the horticulturist will also acknowledge that it would be absurd to expect success in his crops without attending to the heat of his beds, his walls, or his vinery: and why should the manufacturer imagine that there can be any chemical operation in which the degree of temperature is of little moment?

Formerly the brewer had no certain guide to determine when the water was cool enough for mashing the malt, and the fermentation of the wort was conducted only by guess, which occasioned frequent failures and disappointments. He has, however, in the thermometer, now found an unerring guide.

In the preparation of vinegar, the manufacturer depends chiefly upon the sun for the additional temperature which he requires for completing his process. In large establishments, therefore, a great space of land is allotted for the exposure of the casks to its influence. There are, however, some proprietors of vinegar-yards who have found by experiment that the vinegar sooner acquires its maximum of acidity by being kept in a more regular temperature than can be obtained by the sun's rays, since hot days are frequently succeeded by very cold nights.

Such manufacturers, having erected stoves and prepared rooms for the reception of the vinegar, keep it at that exact temperature which they have proved to be best adapted to the process, and find they can finish the work in less than two-thirds of the time usually required for perfecting the business. How easy then would it be for every manufacturer to make this experiment for himself, and ascertain by a few trials what is the proper temperature for conducting the process to the greatest advantage, and in the least time!

Few processes require a more strict attention to temperature than the crystallization of salts. Some require a hot, others a cold situation; and I am not acquainted with any one species that does not give finer crystals when set to shoot at its own peculiar degree of temperature, in preference to all others.

The solution of a salt is also as much governed by temperature as its crystallization; and it is on a knowledge of this principle that the separation of one species of salt from another generally depends. The refining of saltpetre may be mentioned as a familiar instance. In this operation the crude nitre, or rough petre as it is called, is dissolved in hot water, nearly to the point of saturation. Part of the water is then evaporated by boiling; and as the liquor becomes concentrated, the muriate of soda, which is nearly as insoluble in hot as it is in cold water, separates itself from the nitre, and precipitates. This is successively removed as it falls, and the boiling is continued till the operator is satisfied that all the muriate has fallen: the hot liquor, which contains the purified nitre in a state of solution, is then drawn off into coolers, that salt may crystallize.

In the manufacture of earthenware and porcelain many different temperatures are required, according to the nature of the articles, and the progress which has been made in their preparation. In connexion with this subject it may also be observed, that the large glass-house crucibles (according to the present management) require two years for drying, previously to their being submitted to the heat of the potter's oven; and that any kind of earthenware which takes frost during its drying, will inevitably prove very brittle.

In the tanning of hides it has always been known that the process went on much better in summer than in winter. How natural then is it to have recourse to artificial temperature! Mr. Brewin, an ingenious tanner in the Borough of Southwark, is the only person that I know of who has profited by this palpable improvement in the manufacture; and he will doubtless be amply repaid the expenses which have been incurred in erecting stoves and building flues, to convey extra heat to the pits in which the hides

are steeped; for the quality of his leather is much improved, and the process is now shortened by several months.

The working cutler, when he has iron and steel to forge of good qualities, knows that his sole dependence for the excellence of the tools he fabricates, is upon the degree of temperature at which the work is conducted in its different stages. He knows that a sword must be tempered at a heat very different from a pen-knife, an adze different from a saw, and a watch-spring different from a lancet; but the pyrometer has not yet been employed by these manufacturers, and to this circumstance the difficulty and uncertainty of procuring a good edge tool may be attributed. This subject will, however, be further treated of, and some hints for the improvement of the present methods of tempering will be given in the *Essay on Edge-tools*, which constitutes a part of these volumes.

Neither has the thermometer been made use of by the tallow-chandler, although it is evident that he ought never to make any candles without employing that instrument: indeed, the chipping of the outward coat of candles is owing entirely to the neglect of this circumstance, not to say that there is reason to believe that the tallow is often injured, *in the first instance*, by melting it at an improper heat.

The seed-crushers and makers of certain vegetable oils often suffer considerably in consequence of their processes being conducted at an improper temperature. One instance may be taken from the operation of drawing linseed oil. The workman knows that unless the seed be in some measure heated, the oil will not flow; he therefore roasts it over a charcoal fire, and loses ten or fifteen per cent. in weight by that operation. If there be the least want of care, the loss will be much more considerable. In ascertaining by actual experiment what is the temperature that is really necessary, this process, by a proper arrangement, might be managed with as much certainty as any other.

A bushel of foreign linseed weighs about 50lbs.; a bushel of English seed is usually from 60 to 62lbs. In roasting over a charcoal fire to prepare it for the mill, the former generally loses $5\frac{1}{2}$ lbs. and the latter 6lbs.; that is, when the oil which comes from the mill is weighed with the oil cake, there is commonly this deficiency. It strikes me, that if the seed were to be heated by steam, no part of it would burn, and consequently the loss would be very inconsiderable. A still greater saving might also be introduced into this manufactory, were the oil cake itself to be heated by steam; because this would enable the operator to grind it a second time, and thus express from it more of the oil.

An attention to temperature is also of great importance to the dealer in Greenland whale oil, who might increase the profits of

his trade very much by preparing his oil for sale when the weather is suitable for the operation. This kind of oil is always purified by passing it through large flannel bags, which retain the impurities, and suffer the finer parts to percolate through them. When the oil has undergone this treatment, it is called *bagged* oil, and is then deemed fit for sale. At a low temperature, a considerable quantity even of this latter kind would concrete, and might be separated by similar means; whereas in a warm atmosphere this dissolves, and being less inflammable, very much injures the oil for burning.

By proper attention to this circumstance, all the oil which is designed for burning might be very much improved, and the portion thus separated from it, would be worth more to the soap manufacturer for making yellow soap, than similar oil which had not undergone this process. I conceive that an oil-merchant would do well always to bag different oils in different seasons; though many experiments might be necessary before it could be ascertained what was the exact temperature at which the respective kinds would most copiously deposit this feculence.

Madder is an article of great consumption throughout Europe. It is chiefly cultivated in Holland, where it enriches the farmer, and is a considerable source of profit to the Dutch merchants. Plantations of madder have also been made in this country, and the thing has been attempted in France; but it failed, as I understand, in both countries, from the circumstance of the growers not knowing the proper temperature at which the stoves ought to be kept for drying it.

This might surely be ascertained by common means; and if the circumstance of making experiments during the time of harvest should be an objection, how easy would it be for an enterprising agriculturist to procure a person from Holland to give him the necessary instruction!

When the French minister was informed that the workers in silk, although they knew how to prepare it for the woof, were in the habit of importing organized silk from Piedmont, to serve as a chain for their stuffs, because they were ignorant of the method of drawing the silk from the cocoons, he did not hesitate about the proper remedy, but invited the celebrated Vaucanson into France, who not only gave him the information he wanted on that particular point, but invented a machine for platting the stuffs of gold and silver, and giving them the brilliancy of those of the Levant. Thus, by the aid of an ingenious foreigner, the French nation acquired a new and very considerable branch of commerce¹.

¹ Carrard's *Memoir*, presented to the Literary Society of Berne, page 328.

In dyeing woollen cloths with indigo, the blue is more intense, and the colour more permanent, when the vat is used cold. Of these facts no dyer is ignorant; and yet it is a common practice to employ heat, because this makes the indigo go much further, and the colour strike quicker. I would suggest whether it is not likely that there may be one certain temperature at which the indigo would be completely exhausted, and yet the permanency of the dye not impaired.

In the china-blue dipping, one of the processes of calico-printing, the temperature of the lime-vat is of the utmost importance. When the lime is slacked for this purpose, and the vat is prepared with it, there can be no certainty that it will properly fix the printed indigo in the fibres of the cloth, unless it be left at rest till it become as cold as the surrounding atmosphere. To conduct this process with certainty, a thermometer is indispensable; for, as I have understood, the indigo is either fixed or spoiled at the first immersion.

Printed calicoes sometimes sustain an injury by not being stoved at a proper temperature. The common heat of the stoves is about 90° . If they are suffered to rise much above that standard, there is great danger of the acids which have been employed in forming the printed colours injuring the fabric of the cloth, and rendering it tender. On the contrary, some of the colours would spread or enlarge, and perhaps run the one into the other, if the temperature of the stove were allowed to fall, and the calicoes to become cold before they were cleansed of the superfluous mordants.

In the neighbourhood of Rochdale in Lancashire, and in some parts of Yorkshire, the clothiers dye yellows and oranges with the common heath, or ling as it is sometimes called, which is taken from the moors and uninclosed common fields. They mow it when in full flower, about the time of hay harvest. It is spread out to dry as they do hay, and is then laid up in ricks or barns in the same manner.

This vegetable produces by means of a tin mordant, a more beautiful yellow on woollen cloths, than either weld, quercitron-bark, or fustic; the colour being not only brighter, but much more intense than what can be procured from either of those dyes. This colour is, notwithstanding, of very little real value, because it will not bear the action of the sun and air like that produced from weld, nor even so well as the yellow from fustic.

The manufacturers, therefore, invariably dry the goods which are dyed with heath, under cover and in the shade. A very large quantity of coarse cloths, called *bockings*, are dyed with this cheap vegetable substance for the American market; and as the ling has been used in dyeing these kinds of cloth, only a few

years, I fancy the American consumers have not yet learnt to distinguish the goods which are dyed with heath from those which are dyed with fustic. I relate these circumstances merely for the purpose of suggesting whether there may not be some particular temperature at which the heath may be used so as to give a *permanent* dye.

A very excellent yellow may also be given by the quercitron-bark; but if a printer of calicoes be desirous of getting the very finest colour, it can only be procured by making the decoction of the bark, at a very low temperature¹. If, for instance, the colour be extracted from the wood by a heat of about 86°, the goods may be dyed with this decoction at 200° or 205°; but if the colour be extracted at a higher temperature than 86° or 90°, the liquor will inevitably acquire more or less of a brown colour. A high temperature separates the tan² as well as the colouring matter, and the tan which is developed, much deteriorates this very useful and beautiful dye.

The quercitron-bark is also employed in dyeing *woollen* cloths, and for this purpose the dye may be extracted at a temperature somewhat higher than it is ever advisable to use it for printing calicoes: but if these woollen goods be afterwards *hot* pressed, which is a customary process in finishing them for the market, the colour will be changed to a brown; whereas, by submitting the same kind of goods to the action of a *cold* press, the colour is never impaired. Here the variation in the treatment produces such difference in the effects, that the most unscientific workmen are absolutely compelled to attend to temperature.

It has been discovered that the solvent power of water in some cases is very much increased by giving it a temperature above that of 212°. For instance, if it be heated in closed vessels to 220°, it is much more efficacious in bleaching cotton goods than water is, merely at a boiling heat. This, however, can only be accomplished by pressure. I mention the circumstance in this place, because I conceive the principle to be important, and that it might be applied with advantage to many other useful purposes. It is true, that this additional temperature can never be

¹ The most permanent yellow dye we know of is procured from the *weld*. I have often made experiments on extracting the colour from this plant, but I never observed that the beauty of the dye was in the least impaired by digesting the plant in water at any temperature, or even by boiling it.

² I have found that a small portion of muriate of tin will precipitate the tanning principle from vegetable decoctions; but I have not yet made such experiments as will warrant my giving particular directions. In cases where it would be prejudicial to employ muriate of tin, a little isinglass might probably be substituted with propriety, on the principle of the affinity which tan has for gelatine.

imparted to water without employing artificial pressure, as I have remarked; but we know so little of what changes might be effected in the properties of bodies by treating them with caloric under the pressure of several atmospheres, that nothing surely can be more deserving of a diligent and patient investigation.

It is well known how difficult it is to fuse chalk or marble, because, when these substances acquire a certain temperature, the carbonic acid escapes, and they become lime. Sir James Hall, nevertheless, effected the fusion of chalk at a very moderate temperature, by employing a sufficient pressure to prevent the separation of its carbonic acid and water, and in this way he converted the chalk into perfect marble. The detail of these very interesting experiments and others on the cooling of basalt will be found in the fifth and sixth volumes of the *Edinburgh Philosophical Transactions*.

Some very unexpected results have also been produced by the different methods of cooling certain mineral substances which had been reduced to a state of fusion. About seven hundred weight of the *Rowley rag*, a species of basalt, was fused in a common reverberatory furnace, by the late Mr. Gregory Watt, who carefully noticed the changes which it underwent during its different stages of cooling, and communicated the result of his observations to the Royal Society.

This stone is found in the neighbourhood of Rowley in Staffordshire: the village stands upon it. It is of a dark gray colour, and, according to Dr. Withering, it consists of 48 silex, 32 of alumine, and 20 oxide of iron. It is so hard, that Birmingham and some other towns in the neighbourhood are paved with it. It is sometimes employed to mix with the materials for making the common black bottle-glass.

The basaltic mineral in the experiment just mentioned, melted easily; and when a portion of it was taken out in a state of fusion, and cooled quickly, it produced a very hard, opaque black glass¹. When the fire had been continued for six hours, the chimney was closed, and the whole surface of the liquid mass remaining in the furnace was covered with heated sand; after which, eight days elapsed before the whole substance was sufficiently cool to admit of examination.

On removing the indurated mass from the furnace, it exhibited very different appearances; according to the varied action of the heat; and that which had cooled the slowest, was of a dull dark

¹ I believe any of the common bottle-glass may be reduced to a stony substance, by first melting it, and then cooling it very slowly; and that it may afterwards be restored to its shining, vitreous appearance, by remelting it, and then abstracting the caloric with rapidity.

gray colour, very similar in appearance to the original rag-stone. In one case a rough granulated substance is produced, and in the other a shining and smooth glass; and though the difference is so striking, it is occasioned entirely by the variation in the length of the time allowed to this matter for its reduction of temperature.

I have examined some of the specimens which were taken from the furnace at different times during the experiment; and the difference in their appearance is as great as could well be conceived. They were presented to me by a relation of Mr. Watt, soon after the experiment was performed.

From the discovery of these facts, Mr. Watt has endeavoured, in a very philosophical way, to account for the regular figure of the natural basaltic columns, and even for their regular articulations. His reasoning is extremely ingenious; but the reader must be referred for further particulars to the memoir itself, which may be seen in the *Philosophical Transactions* for 1804.

It has been ascertained that steel contains more carbon than wrought-iron, though less than cast iron. From the knowledge of this fact, an ingenious manufacturer at Chesterfield has invented a new mode of making cutlery, and certain other implements in cast iron, and afterwards converting them at pleasure to a substance resembling either wrought iron or steel. This he effects by burying the respective articles of cast iron in a mass of native oxide of iron previously pulverized, and submitting the whole to a long continued heat.

In this operation the oxygen of the oxide combines with the superfluous carbon of the cast iron, and, forming carbonic acid or carbonic oxide, escapes, and leaves the metallic articles in the state of wrought iron or steel, as the operator desires.

This process, which in general answers very well, sometimes will entirely fail, and disappoint the artist. This I should ascribe to its having been conducted at an improper temperature. For if too little heat be given, the native oxide does not impart its oxygen; and if the heat be too intense, or continued beyond the proper time, too much of the carbon will be abstracted, and the articles of cutlery which were designed to have the properties of steel, will be reduced to the state of soft wrought iron. A good manageable pyrometer would enable the operator to escape these disappointments.

In the decomposition of the sulphuric salts for the production of alcalies, a business which I formerly carried on to a considerable extent, I was often perplexed by a similar difficulty. Whenever I could superintend the process myself, I could judge tolerably well of the progress of the operation from the appearances which the materials exhibited within the furnaces; but

when the management of the process was left entirely to the workmen, the operation was sometimes very ill conducted, and the alkaline product was of very little value. For, if a sufficient heat had not been duly maintained, the sulphates were not decomposed; if the decomposition had taken place, and the fire was then suffered to go down, the sulphates would in a great measure be regenerated; and if, during the latter part of the operation, the heat became too intense, then the nascent alkali was elevated, and passed away through the chimney, to be dissipated in the atmosphere. Had I been in possession of a good pyrometer, all these evils might have been avoided.

I know of nothing that better deserves a premium than the invention of a simple and cheap pyrometer, calculated for general use, and applicable to the highest temperatures. That invented by Mr. Wedgwood was an instrument of this kind, but unfortunately the method by which he prepared the small cylinders of argillaceous earth is entirely lost. This reminds me, that Guyton has proposed platinum as a material of which a useful pyrometer might be constructed, as it is not fusible at the heat of our furnaces, and would not be eroded by any of the gaseous products evolved by the most intense fires¹.

The want of a good pyrometer is severely felt by the manufacturers of Birmingham. Cases daily occur of losses sustained in consequence of their not knowing how to ascertain the precise degree of heat in high temperatures.—A single instance will be sufficient to explain my meaning.

It has been customary to fit up the best fowling-pieces with touch-holes of gold, because those of iron or steel are soon eroded and worn away by the sulphur of the gun-powder, which unites with this metal and converts it to a brittle sulphuret.

Nothing can be easier than to mould these gold touch-holes properly, and also to fix them firmly within the gun-barrel; but there is an after-process to be performed, which is attended with considerable difficulty. One of the last operations in finishing a gun-barrel is that of hardening the breech, which can only be done by submitting it to a high degree of heat; and if ever the precise degree that is necessary for the process be exceeded, it is ten to one but the gold melts, and the manufacturer has to replace it with another touch-hole.

When such an accident does occur, the workman has the trouble of again softening the temper of the barrel before he can fix another touch-hole to it, and consequently the same expense and risk of hardening it must be incurred, besides the loss of

¹ See *Annales de Chimie*, xlv. page 276; or Nicholson's *Journal*, vol. vi. page 89.

time. Owing to these inconveniences, the gun-smiths have nearly discarded the use of gold, and now make the touch-holes for the best fowling-pieces of platinum, although they cost nearly double the price. I have been informed that Mr. Manton, a very eminent gun-smith of Dover-street, was the first person who employed platinum for this purpose.

In heating madder for dyeing what are called army-reds, the intelligent dyer well knows that he ought to increase the temperature of the liquor very gradually, and therefore he never attends the operation without carrying a thermometer with him. The scientific gardener has one degree of heat for his cucumber frames, another for the vines, a third for his pinery, and others again for the different exotics, as his experience has prescribed. The sugar-refiner has a stove at one temperature for the bastard sugar, at another for the loaves, and at a third for the candy. The maker of varnish, the general manufacturing chemist, the hatter, the calenderer, the colour-maker, and a variety of other artists, are all dependent on the habit which they have acquired of seizing some one particular temperature for the success of their respective operations, and often without being conscious of their obligation to that circumstance. Even in the manufacture of cheese and the churning of butter recourse must generally be had to an increased temperature: neither will the dough properly ferment, which is designed for making bread, unless it be exposed to a temperature generally higher than that of the atmosphere in this latitude.

I trust, however, that enough has now been offered to induce every manufacturer, who may peruse these loose hints, to apply them to his own business, and to consider, whether some of his peculiar processes might not be very materially improved by a variation of the temperature at which they have usually been conducted. This is the chief object I had in view in composing this Essay; and as all the principal observations are founded upon experience and the best information I could procure, I entertain some confidence that it will be acceptable, and prove highly useful, to the British manufacturer.

The superior knowledge of our manufacturers has been the great source of our excellence as a commercial nation; but there is a danger, amid the growing intelligence of the age, of our losing this proud preeminence, unless some spirited individuals, in every class of society, aim at informing the public mind, and exciting that emulation among our respective artists, which is sure to stimulate their exertions and lead them on to perfection.

ESSAY III.

ON SPECIFIC GRAVITY.

NOTHING can be of more importance to those who are entering on the study of chemistry, or desirous of examining the works of Nature with accuracy, than a competent knowledge of the most convenient methods of taking the specific gravity of bodies.

Every man of science who has had much intercourse with the world, must have met with many intelligent people who are entirely ignorant of this subject; and wherever this is the case, it must be a material obstruction to their making any considerable advances in chemical knowledge.

It may perhaps appear superfluous to those who are conversant with chemistry, to undertake to explain what they themselves so well know, that they cannot so much as recollect the time when it was not known to them. There are, however, many who are so entirely unacquainted with any of the modes of taking specific gravities, that they cannot even explain how absolute differs from specific weight: to such readers therefore no apology will be necessary.

Gravity may be defined to be that property inherent in all bodies which gives them a tendency towards the centre of the earth, and which enables us to measure the quantity of matter in any particular mass, by means of the balance. The amount which the balance thus indicates is said to be the *WEIGHT* of that body. This is what we call the *absolute weight*, or the absolute gravity of any particular substance, to distinguish it from the *specific weight*; or, as it has sometimes been called, its *comparative gravity*.

By *SPECIFIC GRAVITY* is meant the relative weight of any substance as compared with the weight of an equal bulk of another, which we agree to call the standard; for which purpose all nations have fixed upon water as unity. Thus the specific gravity of one body is less or greater than that of another, though their absolute weights may be the same. The specific gravity of a body is in a direct ratio of the mass, and in an inverse ratio of its bulk.

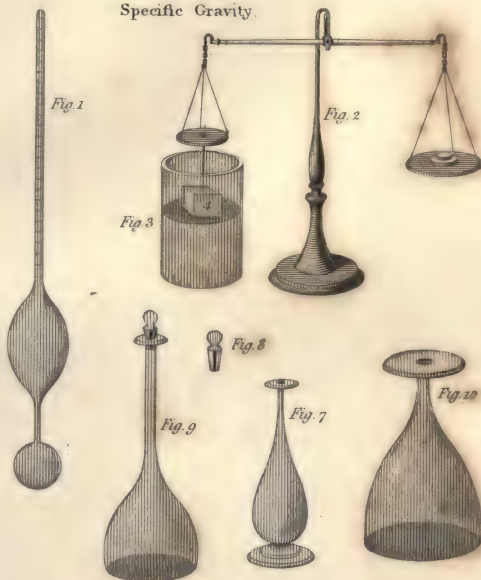
The method of ascertaining quantities by means of the balance was known in the remotest ages¹; but a long period

¹ "Just balances and just weights shall ye have, I am the Lord your God." *Leviticus*, xix. 36. "The spear-head of Goliath weighed six hundred shekels of iron." *1 Samuel*, xvii. 7. "Who hath weighed the mountains in scales, and the hills in a balance?" *Isaiah*, xl. 12.

CHEMICAL ESSAYS.

Plate 4.

Specific Gravity.

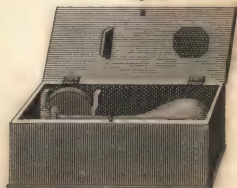


Carat Weights



Fig. 5

Fig. 6



S. Parkes del.

Jas. Davis sculp.

- | | |
|----------------------------|------------------------------|
| 1. An Acometer..... | 6. Knight's Gravity Box.. |
| 2. Hydrostatic Balance... | 7. Knight's Gravity Botle... |
| 3. Water Jar..... | 8. A Peculiar Stopper.... |
| 4. Cube of Glass..... | 9. Nicholson's Bottle..... |
| 5. Set of Carat Weights... | 10. Parkes's D..... |



probably elapsed before mankind acquired any correct idea of distinguishing between the absolute and the comparative weight of bodies ².

Even the great Archimedes, who lived only in the third century before Christ, knew of no method of taking the specific gravity of the precious metals, so as to ascertain the amount of their adulteration; and it was only by long thought that he was at last enabled to succeed. The mode which he devised is minutely described by Vitruvius ³, and his account has been translated for the General Biographical Dictionary, under the article "Archimedes."

When Archimedes had made himself acquainted with the nature of specific gravity, he wrote two books entitled *De Insidentibus Humido*, of which the Latin translation is yet extant, though the original in Greek be lost.

The letter from Synesius to the female philosopher Hypatia, shows that it was understood how to take the specific gravity of water so early as in the fifth century. And Quintius Rhemnius Palæmon, who was a teacher at Rome in the reign of Tiberius, has in his fragment entitled *De Ponderibus et Mensuris*, made the following observation on the comparative specific gravities of water, wine, oil, and honey.

— Libræ, ut memorant, bessem sextarius addet,
Seu puros pendas latices, seu dona Lyæi,
Addunt semissem libræ labentis olivi,
Selibramque ferunt mellis superesse bilibri.

On the revival of learning in Europe, we hear nothing of the examination of bodies by their specific gravities, until this was recommended by Lord Bacon and the Honourable Mr. Boyle. The oldest table of specific gravities now extant, was compiled by the first of these eminent philosophers. It will be found in his tract entitled *Historia densi et rari*, printed in the second volume of his Works in folio, London, 1741, page 69. The methods which he pursued in order to form this table were as follow. Having formed a perfect cube of pure gold of an ounce weight, he caused cubes of the same size to be made of various other materials, and by weighing these against each other he ascertained their relative specific gravities. In regard to fluids, he found their specific gravities by weighing them in hollow cubes of silver, which he had made for this express purpose.

Half a century afterwards Mr. Boyle wrote on the subject, and showed the advantages which a student must derive in his

² Pliny ascertained the relative weights of several sorts of grain, as may be seen in his *Natural History*, book 18. Vitruvius, who was contemporary with Pliny, has also given the weight of a known measure of mercury, viz. that of four Roman sextarii. *Architectura*, lib. vii. cap. 8.

³ *Architectura*, lib. ix. cap. 3.

examination of minerals, and in his other chemical pursuits, from the habit of paying a constant attention to the specific gravity of the several substances which should come under his observation. Other philosophers of Britain then caught the idea, and the practice has been continued ever since by a few illustrious men, such as Newton, Hales, Black, Lewis, Cavendish, and Priestley; and now by all who make any pretensions to cultivate the sciences.

The experiments by Sir Isaac Newton on specific gravity, appear to have been undertaken with a view to his inquiry respecting the densities of bodies when compared with their several refractive powers. The result of these experiments led him to conclude that those transparent substances which are the most refractive, always contain some combustible substance. Hence he concluded that water must be a compound body, a conjecture which has been most fully verified by subsequent discoveries, and shows what extraordinary powers of comprehension of mind he must have possessed, for at that time every philosopher supposed water to be one of the undecomposable bodies, or simple elements of nature¹.

The introduction of this art must, however, have been somewhat later on the continent of Europe; for an eminent French chemical writer tells us, that it was never employed with them in the analysis of minerals till the time of Buffon², who was the first to acknowledge its importance, and render it useful.

Although Buffon may have been the first philosopher in France who attended to specific gravity in the analysis of minerals, it was employed elsewhere in the examination of metals and for other purposes many years before his time.

Marinus Ghetaldus, a nobleman of Ragusa, published a treatise at Rome in 1603, entitled *Promotus Archimedes, &c.*, wherein he gives a comparison between the specific gravities of water and eleven other different substances. In the year following, Baptista Villalpandus published his *Apparatus Urbis Hierosolymitani*, in which he exhibits a table of the proportional weights of all the metals which were then known, and of some other substances. Marinus Mersennus printed a similar table at Paris in 1644, in which he makes gold 100, and water $5\frac{1}{3}$. In the year 1699, M. Homberg read to the Royal Academy of Sciences at Paris, a memoir, showing "how to discover exactly how much one spirit weighs more than another³."

¹ Sir Isaac Newton's table of specific gravities, consisting of 22 articles, was published in his *Optics*, 4to, London, 1704.

² This illustrious man spent fourteen hours a day in study. At five in the morning he retired to a pavilion in his vast gardens, and he was then inaccessible. Prince Henry of Prussia called this retreat the cradle of natural history.

³ See *Hist. Roy. Academy* for 1699, or the 4to *History of the Works of the*

Specific gravity may be considered to be merely another term for the comparative density of bodies; and as the nature and properties of a great variety both of solids and fluids depend in a great measure upon their density, nothing surely can be of more consequence in the examination of natural and artificial substances, than an attention to their specific gravities.

It is thus that the purity of some of the metals, and the value of many liquid preparations, are determined; and thus only can we decide the classification of some minerals when they are not subjected to a regular analysis.

To determine the purity of ammonia, the goodness of alcohol, the strength of other ardent spirits, and the concentration of the mineral acids, their manufacturers entirely rely upon the respective indications which their specific gravities afford them.

In the preparation of alkaline lyes for the manufacture of soap, the operator has to determine the quantity necessary for each operation, and the specific gravity of the solution is his only guide. The makers of Roman vitriol, Epsom, Rochelle, Glauber and other salts, have no proper criterion for ascertaining the strength of the several liquors which they have prepared for crystallization, but that of their specific gravity.

The strength of a variety of metallic solutions, and the concentration of many of the fluids which are employed in chemical operations as solvents for other bodies, can be decided only by the same means.

The makers of oil of vitriol have no other way of knowing when the acid is in a proper state to be removed from the chambers of combustion; the calico-printer, who concentrates his own lemon-juice, has nothing else to direct his decision in determining whether the citric solution be fit for this or that particular style of work; nor does the modern bleacher, who is careful in his operations, ever dare to use the liquid chloride of lime, till he has reduced it to that particular specific gravity at which he knows it may be used with safety.

Even the malleability, tenacity, and hardness of some of the metals, and the volatilities of many fluid substances, may be ascertained or conjectured by an attention to their respective specific gravities; but to enumerate more individual instances would be useless, as I conceive the importance of the subject under consideration must be fully apparent.

It has been before remarked, that specific gravity is only another name for comparative gravity, the absolute weight of the substance under examination being always compared with that of

Learned, vol. iv. 1702, page 652. Professor Musschenbroek of Utrecht published a large table of specific gravities in his *Elementa Physicæ*, 8vo, Leyden, 1734.

some other substance exactly of an equal bulk. In fixing this standard, water presented itself as the most convenient substance; and this, as I before stated, is now generally employed as the datum from which all calculations of specific gravity proceed, water at the temperature of 60° being always called 1.000.

According to the experiments of Professor Robinson of Edinburgh, a cubic foot of distilled water at the temperature of 55° weighs 998.74 ounces avoirdupoise, of 437.5 grains troy each, which is only one ounce and a small fraction less than 1000 avoirdupoise ounces, so that rain water at the same temperature will weigh, as has been stated elsewhere, pretty nearly 1000 ounces¹.

Some excellent directions for the choice of an accurate pair of scales for philosophical purposes will be found in Dr. Ure's Chemical Dictionary, article Balance; and a very ingenious mode of making most minute and accurate weights is described by Lewis in his Commerce of the Arts, p. 544. It will therefore not be necessary for me to enlarge on this branch of the subject. Decimal weights are the most convenient for general philosophical purposes. These are usually sold in boxes from 1000 grains down to the tenth of a grain.

In estimating the specific gravity of fluids, it is usual to procure a phial with a narrow neck, to fill this phial up to the small part of the neck with two, four, eight, or some determinate and easily divisible number of ounces, or any other known weight, of pure water, and then to mark the neck of the bottle with a diamond, precisely at the spot to which the water ascends within it. The bottle being thus prepared, and the quantity of water which it holds up to the fixed mark being remembered, it is ready for use.

When any liquid substance is to be examined, all that is necessary is to pour into the bottle as much of the liquid under examination as shall exactly rise up to the mark on the neck, and then to weigh it accurately, and calculate the difference by the common rule of three. For instance, if it weigh exactly the same as an equal bulk of water, it is said to be of the specific gravity of water. But if the bottle hold four ounces of water, and the same measure of some other fluid should weigh *six*, it is evident that this fluid is half as heavy again as water, and water being 1.000, this fluid will be noted to be of the specific gravity of 1.500; because $4 : 6 :: 1000 : 1500$. The bottle usually employed by the soap-boiler, to ascertain the strength of his alkaline lyes, is of this kind.

¹ For further information consult Mr. John Dalton, "On the Density of Water," in Nicholson's *Journal*, vol. x. p. 93; Count Rumford, in the same work, vol. xi. page 225; or Dr. Kelly's *Universal Cambist*, 4to, London 1811, vol. i. page 260.

Another method of ascertaining the specific gravity of fluids, is by noting the weight of some solid, such as a cube of glass, in distilled water, and then weighing the same substance in the liquid to be examined. These weights should be noted in grains, and by dividing what the solid loses in the fluid by what it lost when it was weighed in the water, the quotient will be the real specific gravity of the liquid. The specific gravity of fluids is also found by the areometer, a mode that is attended with much less trouble than either of the former, but it is not likely in all cases to be equally accurate.

This instrument is a graduated glass tube, with a bulb at one end of it, and so contrived, by being balanced with mercury or lead, that it may swim in the fluid, in a perpendicular position. The specific gravity is shown by the degree marked on the stem of the instrument, to which it sinks in the fluid to be examined, and this will consequently always be lower in proportion as the liquid is lighter. The areometer of Baumé, which has long been the instrument in common use in France, is upon this construction.

The areometer is an instrument of great antiquity. It was formerly supposed to have been invented at the close of the fourth century by Hypatia, the celebrated mathematician of Alexandria; but Usebe Salverte, in a memoir on this subject in the twenty-second volume of the *Annales de Chimie*, has shown that it was undoubtedly invented by Archimedes. This writer has given a Latin description of the instrument, from an author of great antiquity, and from this it appears that the ancient areometer was very similar in form to the modern.

The first instance I have met with of the use of the term areometer is in the *Philosophical Transactions*, No. 262; in which it is applied to an instrument invented by Homberg, and employed by him in conducting some experiments on specific gravity which he has related in the *Memoirs of the Academy of Sciences at Paris* for the year 1699. The instrument is thus described by Dr. Davies, a writer to whom I am under great obligations for many hints of which I have availed myself in this Essay:—"It was an instrument," says the Doctor, "which Homberg had contrived and called an *aræometer*, it being a large phial, to which he had adjusted a long and slender stem, whereby he could to good exactness determine specific gravities, when it was filled with equal bulks or quantities of the several fluids he proposed to examine². It will, however, be perceived

² See *Tables of Specific Gravities*, by Richard Davies, M.D. 4to, London, 1750, page 12. For an account of an improved areometer for spirits see the *Philosophical Transactions*, No. 413, page 277, or Baddam's *Memoirs of the Royal Society*, vol. ix. page 47.

that this instrument is entirely on a different principle from the one now known by the name of an areometer.

The late Mr. Nicholson made a great improvement in the areometer, having adapted it to the measure of the density of solids as well as fluids. It is described in the second volume of the *Manchester Memoirs*, and a plate of it is given in the first volume of Nicholson's *4to Journal*¹.

In France the areometer has long been in use. Those constructed by Baumé were generally employed; and as they are very frequently mentioned in the writings of the French chemists, I have deemed it advisable to explain the principle on which they were founded.

In forming this instrument he had recourse to a process similar to that of graduating the stems of thermometers from two fixed points. The first of these points was obtained by immersing the instrument in pure water. At that point of the stem which was intersected by the surface of the fluid, he marked zero, or the first of his graduation, and this commenced at or near the upper extremity of the stem.

He then provided a number of solutions of pure common salt in water: these solutions contained respectively one, two, three, four, &c. parts of the dry salt, and in each solution the quantity of water was such as to make up the weight equal to one hundred parts in the whole; so that in the solution containing one part of salt, there were ninety-nine parts of water; in the solution containing two parts of salt, there were ninety-eight parts of water, and so on with the rest. The instrument was then plunged in the first solution, in which of course it floated with a larger portion of the stem above the fluid, than when pure water was used. The fluid, by the intersection of its surface upon the stem, indicated the place for marking his first degree; the same operation repeated, with the fluid containing two pounds of salt, indicated the mark for the second degree; the solution of three pounds afforded the third degree: and in this manner his enumeration was carried as far as fifteen degrees. These first degrees applied with the compasses repeatedly along the stem, served to extend the graduation as far as was required. This instrument, which is applicable to the admeasurement of densities exceeding that of pure water, is distinguished by the name of "the areometer for salts." His areometer for spirits is formed upon the same principle; but in this the counterpoise is so adjusted, that most part of the stem rises above the fluid when immersed in pure water: consequently the graduations to ex-

¹ See *Memoirs of the Literary and Philosophical Society of Manchester*, vol. ii. page 370; and Nicholson's *Journal*, vol. i. page 110.

press inferior densities are continued upwards on the stem, instead of downwards as in the former instance.

Here a solution of ten parts by weight of salt, in ninety parts of water, afforded him the first point of zero; and the mark indicated by pure water he called the tenth degree; whence by equal divisions the remaining degrees were determined.

Baumé's Areometer for Salts.

Baumé's Areometer for Spirits.

Temperature 55° Fahrenheit.		
Deg.	Sp. Gr.	Deg. Sp. Gr.
0	— 1.000	39 — 1.373
3	— 1.020	42 — 1.414
6	— 1.040	45 — 1.455
9	— 1.064	48 — 1.500
12	— 1.089	51 — 1.547
15	— 1.114	54 — 1.594
18	— 1.140	57 — 1.659
21	— 1.170	60 — 1.717
24	— 1.200	63 — 1.779
27	— 1.230	66 — 1.848
30	— 1.261	69 — 1.920
33	— 1.295	72 — 2.000
36	— 1.333	

Temperature 55° Fahrenheit.		
Deg.	Sp. Gr.	Deg. Sp. Gr.
10	— 1.000	26 — .892
11	— .990	27 — .886
12	— .985	28 — .880
13	— .977	29 — .874
14	— .970	30 — .867
15	— .963	31 — .861
16	— .955	32 — .856
17	— .949	33 — .852
18	— .942	34 — .847
19	— .935	35 — .842
20	— .928	36 — .837
21	— .922	37 — .832
22	— .915	38 — .827
23	— .909	39 — .822
24	— .903	40 — .817
25	— .897	

In Great Britain and Ireland the specific gravity of ardent spirits is determined on another principle, and various instruments, called hydrometers, have been used for the purpose. Here, unfortunately, the specific gravity is not calculated from that of water, but from the strength of an arbitrary spirit, which the Excise Board calls proof spirit, the specific gravity of which is about 0.933. The relation which all other spirituous liquors have to the standard, is expressed by saying they are so much above or under hydrometer proof.

For instance, a spirituous liquor is said to be ten per cent over hydrometer proof, when it is so strong that one hundred gallons of it will admit an addition of ten gallons of water to reduce it to the strength of proof; and it is considered to be ten per cent under proof, when one hundred gallons contain ten gallons of water more than is contained in proof spirits.

In chemical laboratories it would be inconvenient to depend solely on any instrument of the kind just described; for the range from the specific gravity of pure liquid ammonia to that of concentrated sulphuric acid is so great, that several different areometers would be required; it being almost impossible to construct

² See Baumé's *Elémens de Pharmacie*, 1784, page 410; or Nicholson's *4to Journal*, vol. i. page 37.

ought always to be employed, as a variation in this respect will inevitably affect the result. A philosophical friend of mine has been in the habit of using water drawn from a deep well for such purposes, finding such water, in all seasons, to be of the same temperature, provided he employed it as soon as it came from the well. Nearly a century ago Mr. Charles Labelye, civil engineer, ascertained the specific gravity of several sorts of stone and other materials used in building. These were afterwards printed in *Dodson's Calculator*, 8vo, London 1747, and may even now be referred to by builders with advantage.

The works of most eminence on the subject of weighing hydrostatically were published in the following order. *Medicina Hydrostatica*, by the Honourable Robert Boyle, 8vo, London 1690; Sir Isaac Newton's *Optics*, 4to, London 1704; *The Young Mathematician's Guide*, by John Ward, 1706; *Hydrostatical and Pneumatical Lectures*, by Roger Cotes, A.M. Plumian Professor of Astronomy, &c. at Cambridge, 8vo, 1707; *Hauksbee's Hydrostatical Lectures*, 4to, 1710; *Lectures on select Subjects in Mechanics, Hydrostatics, &c.*, by James Ferguson, 8vo, London 1760, together with *A Supplement to this work*, 4to, London 1767. A third edition of Mr. Cotes's *Lectures* was printed in London in 1775; in which there are some very minute and useful directions for weighing a variety of substances hydrostatically.

Dr. Jurin, who was Secretary to the Royal Society in the beginning of the last century, has also published some very useful remarks respecting the cautions necessary to be used in examining the specific gravity of solids, when weighed hydrostatically; for want of attending to which, several kinds of bodies, from their pores being filled with air, have appeared to be considerably lighter than they really are. See *Phil. Trans.* No. 369.

This method of weighing, and which can only be employed for solid bodies that are insoluble in water, is commonly conducted thus: The substance to be weighed is hung by a fine hair to one of the arms of a small scale-beam, which has a common scale-dish suspended to the other arm. When the article which is intended to be tried is suspended by the hair, it is accurately balanced by grain-weights, and the weight of it noted. It is then taken, still suspended to the arm of the balance, and immersed entirely in water, which will destroy the equilibrium, and occasion the opposite scale to preponderate. Weights are then taken out of the scale till the balance is restored; and the amount of the weights which it is necessary to take out to restore the equilibrium, shows the difference there is in the weight of the substance when weighed in air and in water.

When the specific gravity of a substance is required, which

cannot be weighed in water, because it is soluble in that fluid, it may probably be weighed in some liquor that will not dissolve it. Thus, if it be a saline substance, it may probably be weighed with accuracy in a saturated solution of that salt.

It is obvious that, in this method of taking specific gravities, water can be employed only for such substances as are above 1.000, or denser than water; because such bodies would not sink in the water, and it is necessary that they should be completely immersed. When it is required to weigh a body hydrostatically, that is specifically lighter than water, some heavier substance must be attached to it, and its weight also must be taken into account in making the calculation.

A more ready way to determine the specific gravity of solids, when circumstances will admit of it, is to fill a phial with water, and note the weight of the whole accurately in grains. Then weigh 100 grains of the substance to be examined, and drop it gradually into the phial of water. The difference of weight of the bottle with its contents now, and when it was filled with water only, will give the specific gravity of the matter under consideration. For example, if the bottle weighs 50 grains more than it did when it was filled with water only, it shows that 100 grains of the mineral displace only 50 grains of water, and consequently that it is twice the specific gravity of water.

It was on this principle that Archimedes is said to have discovered the deceit which had been practised upon his relative Hiero the Second, king of Syracuse, by an unprincipled goldsmith who had been employed to fabricate a crown of pure gold for him, as an offering to the gods.

The workman, it seems, had alloyed the crown with a portion of silver, imagining that the fraud could not be detected;—but Archimedes, suspecting that a cheat had been practised, hit upon the following method of ascertaining the fact:

He made two masses, each of equal weight with the crown, one of gold and the other of silver: when he had done this, he filled a large vessel to the brim with water, and put the silver mass into it, upon which a quantity of water overflowed, equal to the bulk of the mass: then taking the metal out, he filled up the vessel again, measuring the water exactly which he put in: this showed him what measure of water answered to a certain quantity of silver.

He then tried the gold in like manner, and found that it caused a less quantity of water to overflow; the gold being less in bulk than the silver, though of the same weight. Having filled the vessel a third time, he then put in the crown itself and found that it caused more water to overflow than the mass of gold of the same weight. From these data he calculated, as he

imagined, how much gold had been purloined, and what silver had been substituted in its stead¹.

This piece of history, which has been related a hundred times in various ways, would not have found a place here, but for the design of ingrafting upon it a very necessary and a very important caution.

A person might conclude, when it had been once clearly ascertained that one of two metals, whose specific gravities differed, was the heaviest metal then known, that there would be no impediment in calculating how much of the lighter metal had been employed in forming an alloy of the two metals: experience, however, proves the fallacy of such a theory.

Mr. William Lewis, the first person who examined this subject with due care, made a great number of mixtures of the different metals; and the result of these experiments shows, "that the specific gravity of a metal can never be with any certainty deduced from that of its mixture with another metal, as a dilatation or contraction of the volume may result from their action on one another; and that when two metals of known specific gravities are melted together, their proportions cannot be found from the gravity of the compound, without a previous hydrostatic examination of known mixtures of them in different proportions, and, consequently, that the celebrated method of calculation proposed by Archimedes is of more limited use than has generally been supposed."

The apparent anomaly in the alloy of gold with silver, Mr. Lewis explains by stating, that the proportions of these metals should be calculated from their respective bulks, and not from their weights. A person who was acquainted with this fact, he says, made great profits in buying gold from the Chinese, who usually employ silver in their alloy of gold².

Mr. Lewis, however, was not the first person who wrote on this subject; for Mr. Hooke had made some experiments before the Royal Society on a mixture of tin and silver, which tended to a result similar to the one which Mr. Lewis afterwards obtained. Dr. Davies also suggested the same idea thirteen years before the publication of the *Commercium Philosophico-Technicum*, which did not make its appearance until the year 1763. "It might be queried," says Dr. Davies, "whether mixed metals do not either rarefy or condense upon mixture, so as thereby to acquire a different specific gravity than the natural law of their composition at first seems to require³."

¹ Vitruvius, lib. ix. cap. 3.

² *Philosophical Commerce of the Arts*, pages 125 and 556.

³ Davies's *Tables of Specific Gravities*, page 29.

In the mixture of crude platinum with silver, it is well known that there is a diminution of specific gravity; and in its mixture with iron, an increase. Tin is specifically much lighter than copper, yet the specific gravity of the compound, bell-metal, is greater than that of copper itself. From inattention to such facts many deceptions might arise, and innumerable errors be committed.

Mr. Scheffer made out a table for determining the quantities of lead and tin in any given mixtures of the two, by taking the specific gravity of the alloy; and this was published in the Swedish Acts for 1755. But as this table was formed without comparison with standard mixtures, it cannot be depended upon, and is consequently of no value.

Having thus shown that the specific gravity of a compound metal can never, with any certainty, be deduced by calculation from that of its mixture with another metal, as a dilatation or contraction of the volume results from their mutual action on each other; it may be observed that just so is it with the *melting* point of a compound metal. Tin melts at 413° of Fahrenheit, bismuth at 476° , and lead at about 612° ; but a certain mixture may be made with these metals, that will fuse at the temperature of 202° . There are also some curious anomalies in the melting points of various mixtures of lead and tin.

The goodness of tin may be generally known by its specific gravity, though it would be erroneous to judge of the ores of tin by the same means, because some specimens of the best ores are of a specific gravity greater even than that of the pure metal itself.

A deception equally great would arise from an attempt to calculate the proportions of many of the mixtures of liquid substances, without having made previous experiments to determine the amount of their condensation by mixture: for, when two liquids unite chemically, the compound has generally a density greater than the mean density.

If we make a mixture of ardent spirit with water, the specific gravity of the mixture will not be a mean specific gravity. Water itself is of far greater gravity than the oxygen and hydrogen gas which compose it. One measure of sulphuric acid and one measure of water, when mixed, will not occupy the space of two measures; consequently the mixture cannot have a specific gravity corresponding to the mean between those of the two original fluids.

It will be remembered, therefore, that to ascertain the specific gravity of a body may serve to furnish some idea of its purity, some substances being increased, and others diminished, in their

specific gravities, by sophistication; that it will indicate the comparative value of certain metallic, acidulous or alkaline solutions, and has innumerable other uses in the hands of the manufacturing or philosophical chemist, some of which have been mentioned at page 105: it does not, however, afford any means of accurately discovering the amount of adulteration, or establishing a proof of the quantities of the components, whether the mixture be fluid or solid.

A method of calculating the mean specific gravity of a compound from those of its component parts has been lately published by Dr. Ure in his *Chemical Dictionary* before mentioned under the article *Specific Gravity*; and in the *Journal of Science and the Arts*, vol. iv. page 151.

Nothing now remains but to notice a distinct method of taking the specific gravity of fluids, which differs in some respects from those already described, and is that which I have adopted in my own *Chemical Manufactory* for many years past.

This ingenious contrivance, which originated with Dr. Lewis, was communicated to me by the amiable Mr. Samuel Moore, late Secretary to the Society for the Promotion of Arts, Manufactures and Commerce, who favoured me with a sight of Dr. Lewis's manuscript, and allowed me to make such extracts from it as I conceived might be useful.

In this scheme the specific gravity of a liquor is estimated from the excess of the weight of a certain measure of it, above that of an equal measure of distilled water. For this purpose, a peculiar set of weights, which he called *CARATS*, is to be made in the following manner:

A convenient bottle, with a long narrow neck, being procured, the tare of the bottle is first taken, and a weight made corresponding thereto, as the exact counterpoise: it is then to be completely filled with distilled water at 60° , or till the water rise to a mark made in such part of the neck as shall be found most convenient. A weight corresponding to the net weight of this water is then to be made, and marked 128; after which this weight is to be accurately divided into two equal parts, and a weight made equal to one of these parts is to be marked 64. By continuing the subdivision we shall have the weights, 32, 16, 8, 4, 2, 1, carats; so that each carat, though in some measure of an arbitrary value, must be one hundred and twenty-eighth of the water required to fill such bottle.

When these weights are adjusted, it will be proper to make another counterpoise besides that already described for the tare of the bottle, and this must be an exact balance to both the water and bottle. We then make our estimate in this way:

So many carats as the bottle when filled with any other fluid, exceeds this united weight or *counterpoise*, so many carats strong is such fluid to be estimated.

This small apparatus is equally useful for taking the specific gravities of alcohol, ether, liquid ammonia, oils, or any other fluid body which is *lighter* than water. In such cases, the only variation necessary is to put the carat-weights in the scale with the bottle, instead of putting them with the water-poise; and whatever number of carats may be required for bringing the bottle and the water-poise to an equilibrium, so many carats is the fluid lighter than an equal measure of pure water; and as the perfection of these liquids is in a direct ratio with their levity, their true value is at once demonstrated.

Soon after I had printed this account of my apparatus for taking the specific gravity of fluids, Mr. Gill informed me that he had formed an apparatus which may be considered to be in some measure an improvement upon mine; and which he thus describes: He has a phial as usual, with a ground glass stopper, having a groove cut upon it to let the air and superfluous fluid escape on closing the orifice. The weights are contained in a metallic box, the lid of which is made to be exactly equal in weight to the empty glass bottle with its stopper, whilst the other part of the box (weighing 128 carats) is equal to the weight of the distilled water which the bottle at a certain temperature is capable of containing. His weights consist of one of 64 carats, one of 32, one of 16, one of 8, one of 4, one of 2, and two weights of 1 carat each. The last two are of the same denomination, in order that the amount of the whole may be equal to 128, without which the specific gravity of a fluid equal to 2000 could not be obtained. He has also weights for the half, fourth, eighth, and sixteenth of a carat.

The following is a Table of Carats, with their corresponding degrees of specific gravities, which I constructed many years ago for the use of my own laboratory. For those persons who have been in the habit of calculating specific gravities by the wine-pint, or, to speak more accurately, by a measure holding exactly sixteen avoirdupois ounces of water, as also for those who may not be conversant with the mode of reckoning specific gravities by decimal arithmetic, I subjoin a column of the weights in ounces and drachms. We know it has been decided that the wine-pint holds rather more than sixteen ounces of water; but it is most convenient for all *common* purposes, still to consider it as a measure of sixteen ounces, and this table is constructed accordingly.

Carats.	Fluids heavier than water.	Weight of the wine pint.		Fluids lighter than water.	Carats.	Fluids heavier than water.	Weight of the wine pint.		Fluids lighter than water.
	Sp. Gr.	Oz.	Drms.	Sp. Gr.		Sp. Gr.	Oz.	Drms.	Sp. Gr.
1 =	1.0078	16	2	0.9922	54 =	1.4218	22	12	0.5782
2	1.0156	16	4	0.9844	55	1.4296	22	14	0.5704
3	1.0234	16	6	0.9766	56	1.4375	23	0	0.5626
4	1.0312	16	8	0.9688	57	1.4453	23	2	0.5547
5	1.0390	16	10	0.9610	58	1.4531	23	4	0.5469
6	1.0468	16	12	0.9532	59	1.4609	23	6	0.5391
7	1.0546	16	14	0.9454	60	1.4687	23	8	0.5313
8	1.0625	17	0	0.9376	61	1.4765	23	10	0.5235
9	1.0703	17	2	0.9297	62	1.4843	23	12	0.5157
10	1.0781	17	4	0.9219	63	1.4921	23	14	0.5079
11	1.0859	17	6	0.9141	64	1.5000	24	0	0.5001
12	1.0937	17	8	0.9063	65	1.5078	24	2	0.4922
13	1.1015	17	10	0.8985	66	1.5156	24	4	0.4844
14	1.1093	17	12	0.8907	67	1.5234	24	6	0.4766
15	1.1171	17	14	0.8829	68	1.5312	24	8	0.4688
16	1.1250	18	0	0.8751	69	1.5390	24	10	0.4610
17	1.1328	18	2	0.8672	70	1.5468	24	12	0.4532
18	1.1406	18	4	0.8594	71	1.5546	24	14	0.4454
19	1.1484	18	6	0.8516	72	1.5625	25	0	0.4376
20	1.1562	18	8	0.8438	73	1.5703	25	2	0.4297
21	1.1640	18	10	0.8360	74	1.5781	25	4	0.4219
22	1.1718	18	12	0.8282	75	1.5859	25	6	0.4141
23	1.1796	18	14	0.8204	76	1.5937	25	8	0.4063
24	1.1875	19	0	0.8126	77	1.6015	25	10	0.3985
25	1.1953	19	2	0.8047	78	1.6093	25	12	0.3907
26	1.2031	19	4	0.7969	79	1.6171	25	14	0.3829
27	1.2109	19	6	0.7891	80	1.6250	26	0	0.3751
28	1.2187	19	8	0.7813	81	1.6328	26	2	0.3672
29	1.2265	19	10	0.7735	82	1.6406	26	4	0.3594
30	1.2343	19	12	0.7657	83	1.6484	26	6	0.3516
31	1.2421	19	14	0.7579	84	1.6562	26	8	0.3438
32	1.2500	20	0	0.7501	85	1.6640	26	10	0.3360
33	1.2578	20	2	0.7422	86	1.6718	26	12	0.3282
34	1.2656	20	4	0.7344	87	1.6796	26	14	0.3204
35	1.2734	20	6	0.7266	88	1.6875	27	0	0.3126
36	1.2812	20	8	0.7188	89	1.6953	27	2	0.3047
37	1.2890	20	10	0.7110	90	1.7031	27	4	0.2969
38	1.2968	20	12	0.7032	91	1.7109	27	6	0.2891
39	1.3046	20	14	0.6954	92	1.7187	27	8	0.2813
40	1.3125	21	0	0.6876	93	1.7265	27	10	0.2735
41	1.3203	21	2	0.6797	94	1.7343	27	12	0.2657
42	1.3281	21	4	0.6719	95	1.7421	27	14	0.2579
43	1.3359	21	6	0.6641	96	1.7500	28	0	0.2501
44	1.3437	21	8	0.6563	97	1.7578	28	2	0.2422
45	1.3515	21	10	0.6485	98	1.7656	28	4	0.2344
46	1.3593	21	12	0.6407	99	1.7734	28	6	0.2266
47	1.3671	21	14	0.6329	100	1.7821	28	8	0.2188
48	1.3750	22	0	0.6251	101	1.7890	28	10	0.2110
49	1.3828	22	2	0.6172	102	1.7968	28	12	0.2032
50	1.3906	22	4	0.6094	103	1.8046	28	14	0.1954
51	1.3984	22	6	0.6016	104	1.8124	29	0	0.1876
52	1.4062	22	8	0.5938	105	1.8202	29	2	0.1797
53	1.4140	22	10	0.5860	106	1.8280	29	4	0.1719

Carats.	Fluids heavier than water. Sp. Gr.	Weight of the wine pint. Oz. Drms.	Fluids lighter than water. Sp. Gr.	Carats.	Fluids heavier than water. Sp. Gr.	Weight of the wine pint. Oz. Drms.	Fluids lighter than water. Sp. Gr.
107 =	1.8358	29 6	0.1641	118 =	1.9218	30 12	0.0782
108	1.8436	29 8	0.1563	119	1.9296	30 14	0.0704
109	1.8514	29 10	0.1485	120	1.9375	31 0	0.0626
110	1.8593	29 12	0.1407	121	1.9453	31 2	0.0547
111	1.8671	29 14	0.1329	122	1.9531	31 4	0.0469
112	1.8750	30 0	0.1251	123	1.9609	31 6	0.0391
113	1.8828	30 2	0.1172	124	1.9687	31 8	0.0313
114	1.8906	30 4	0.1094	125	1.9765	31 10	0.0235
115	1.8984	30 6	0.1016	126	1.9843	31 12	0.0157
116	1.9062	30 8	0.0938	127	1.9921	31 14	0.0079
117	1.9140	30 10	0.0860	128	2.0000	32 0	0.0001

Since this Essay was composed, a simpler and more accurate method of taking the specific gravities than any of the above has been brought into very general use with scientific manufacturing chemists. A narrow-necked bottle must be provided, as described page 110, with a ground conical stopper, having a fine indentation filed to allow the fluid to overflow and prevent the existence of air bubbles within the bottle. This bottle must be formed to hold precisely 1000 grains of distilled water. When filled with the fluid to be tried, placed in one scale, and in the other a weight correspondent to the tare of the bottle and stopper, it only requires to take the weight in grains, and every grain above 1000 will form an unit in the third place of decimals; as for instance, if it weighs 1845 grains, its specific gravity will be 1.845, which is the gravity of concentrated sulphuric acid.

Once more, I must inculcate the necessity of attending to the degree of temperature of the atmosphere when the experiment is made, as well as to that of the material to be examined, when its temperature is raised, or diminished, so as to deviate from the former; for we know that the specific gravity of all bodies is greatly influenced by sensible caloric, and their bulk increased or diminished in proportion to the quantity they contain. I repeat, that it is of little avail to ascertain the specific gravity of bodies, if proper attention be not at the same time paid to their degree of temperature; for gases, fluids, and solids, vary in bulk according to the quantity of free caloric contained in them¹.

¹ For an account of the expansion of the gases by heat consult Dalton's *New System of Chemical Philosophy*, part 1. Manchester 1808. A table of the expansion of glass is given by Dr. Henry in his *Elements of Experimental Chemistry*, vol. ii. page 524; and Mr. John Ellicott published "The description and manner of using an instrument for measuring the degrees of the expansion of metals by heat," in the *Philosophical Transactions*, No. 443, page 297. A collection of facts respecting the expansion of wood by heat will be found in a memoir by Dr. Rittenhouse, published in the *Transactions of the American Philosophical Society*.

Mr. Nicholson has stated, that he finds by experiment that the fifth decimal figure changes in *water* at every three degrees of Fahrenheit's thermometer. Other fluids will undoubtedly observe a different ratio; but a manufacturer, to whom it is often necessary to try the specific gravity of one particular liquor, might, for his own use, easily form a table of these variations.

In chemical manufactories it is often necessary to take the specific gravity of a fluid when nearly at a boiling heat. To do this, I have always employed a *stone* bottle of a determinate size, because this ware will endure such a temperature without breaking. I have thought of glass bulbs: but if one of these small instruments be selected which will just swim in a fluid of the specific gravity I want, the same would also swim on a liquor of greater specific gravity, and this might occasion an error of some importance. In like manner, a bulb might be chosen that would just sink in a liquor of a determinate specific gravity, but it would also sink in a lighter fluid, and this might equally produce deception. Mr. London, who has obtained a patent for purifying muriate of soda (rock-salt), has, however, adopted the ingenious expedient of employing *two* bulbs of different weights at once, and by this means he readily determines when his saline liquor is evaporated to the point which is necessary for his purpose. For, if the lixivium be too much diluted, both these bulbs will fall to the bottom; and if it be too heavy, both of them will swim: but when he perceives that the heaviest of these falls and the other swims, he then knows that he may rely upon the liquor being of the medium specific gravity which he requires. I have for years been in the habit of using Twaddell's hydrometers in boiling fluids, taking a little care to immerse them once or twice, to warm them before I leave them in, and holding them for a few moments exposed to the hot steam before I entirely withdraw them. By means of this trifling precaution, I have never in a single instance had one broken, even by servants in taking the gravity of boiling liquids.

When I spoke of the necessity of using the thermometer in taking specific gravities, it was my intention to observe, that the important instrument which is generally employed in Great Britain was constructed by Mr. Gabriel Daniel Fahrenheit, a native of Hamburgh, who came to this country in the year 1724, was elected a fellow of the Royal Society of London, and in that year published "A Dissertation on Thermometers." I state these circumstances merely to give me an opportunity of mentioning, that this gentleman was also concerned in investigating the specific gravities of various bodies, and that while in England he published "A Table of the Specific Gravities of twenty-eight several Substances," with various observations, in

the Philosophical Transactions, No. 283. If any of my readers should know of a memoir, or an engraved portrait, of this eminent man, I shall most thankfully receive such information. There is no notice of him or of his portrait either in Bromley, Grainger, or Noble, all of which I have carefully examined.

The metals afford the greatest variety in their specific gravities of any order of substances in nature. The following Table, which gives a view of the principal ones arranged according to their specific gravities, I have thought might be useful, and suitable for admission into this Essay.

A TABLE

OF

THE SPECIFIC GRAVITY OF THE METALS.

Platinum.....	21.470	Nickel	8.380
Gold	19.300	Uranium	8.100
Tungsten	17.400	Manganese	8.043
Mercury, frozen.....	14.465	Iron	7.700
Ditto, fluid	13.568	Tin	7.291
Palladium	11.500	Zinc, hammered.....	7.190
Lead	11.350	Do. cast in bars	6.861
Rhodium	10.649	Antimony.....	6.712
Silver	10.474	Tellurium	6.115
Bismuth	9.822	Chromium	5.900
Copper	8.735	Arsenic.....	5.763
Cobalt	8.700	Sodium	0.972
Molybdenum	8.611	Potassium	0.865

ESSAY IV.

ON BARYTES.

IN the year 1774, M. Scheele made some experiments on a mineral called *Marmor Metallicum*, which he found to be a combination of sulphuric acid and a peculiar alkaline earth not as yet described. Gahn also minutely examined this mineral in the year 1775, and both these chemists agreed to denominate the base of it "heavy earth." Scheele then published an account of his experiments upon it in a memoir on manganese, and this work directed the attention of most of the chemists in Europe to the investigation of its nature and properties¹.

Bergman at first called the earth *terra ponderosa*; Weigleb and Sage called it *barogium*; afterwards it was called *barotes*; and at last Bergman named it, from the Greek word "*barus* heavy," *barites*; and with the alteration of a single letter, it has borne that name ever since.

Barytes has never been found native otherwise than in combination with an acid. Its affinity for the carbonic and other acids is such that it cannot exist in nature in a state of purity.

The mineral on which the first experiments were made was a sulphate of barytes, the only native substance which was then known to contain this alkaline earth. This mineral, which has been called *vitriolated heavy earth*, *ponderous spar*, *phosphoric spar*, *baroselenite*, &c., occurs very plentifully in various parts of Great Britain, and in most countries of Europe. Its specific gravity is generally from 4,400 to 4,470. It is perfectly insoluble in water, and is the only barytic salt that is not poisonous.

This native production is found in large masses in the Derbyshire lead mines, where it is distinguished by the name of *carw*; in the Cornish copper mines; at Roye in the province of Picardy in France; in the vicinity of Mount Etna, and in a variety of other places. It occurs in veins nearly four feet wide, traversing the sand-stone in the Isle of Arran, at a small distance from the shore. Also at Pomona in the Orkneys². It is the heaviest native earthy salt with which we are acquainted.

It is composed of different proportions of acid, base and extraneous matter, according to its peculiar locality; whereas the

¹ See Dr. Hoepfner's paper on Sulphate of Barytes in Crell's *Annales*, tom. i. p. 132; or in *Annales de Chimie*, tom. i. p. 217.

² See Jameson's *Mineralogy of the Scottish Isles*, 4to, 1800, vol. i. page 71, and vol. ii. page 232.

CHEMICAL ESSAYS.

Plate 5

A Barytes Furnace

Fig. 1

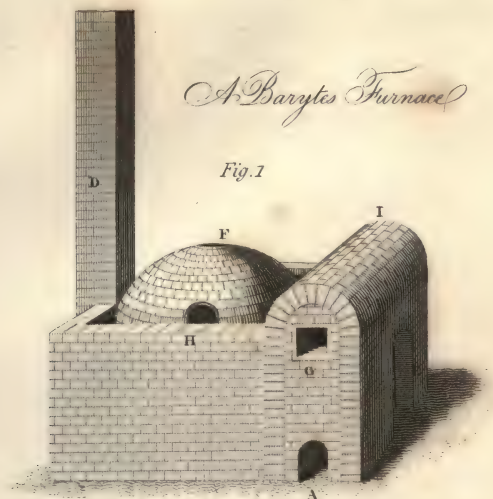
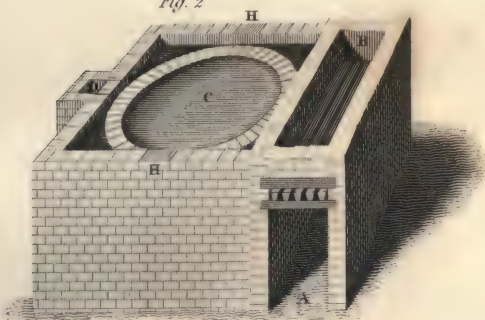


Fig. 2



Ja. Davis sculp.

1 Elevation — 2 Inter.^s of Furnace

- | | |
|-----------------------------|----------------------------|
| A. Ash pit..... | F. Furnace Arch..... |
| B. Fire place..... | G. Fire hopper..... |
| C. Place for the Caule..... | I. Arch of fire place..... |



sulphate of barytes which is formed by art consists of 66 barytes and 34 sulphuric acid³. The native sulphate is sometimes of a flesh colour, and of a foliated texture; but it occurs also in a great variety of crystalline forms and colours. Thus, very beautiful specimens of crystallized sulphate of barytes were formerly procured from the Nutfield fuller's earth pits, at Bletchingly near Godstone in Surry. The workmen found it generally in loose pieces in the midst of the bed of fuller's earth, and called it shining spar.

Besides the places already enumerated, beautiful specimens of the sulphate of barytes are found in some of the northern counties of England. In Mr. Hutton's museum at Keswick in the county of Cumberland, there is a single crystal which is perfectly formed, and weighs 29lbs. 2oz. When weighed hydrostatically it loses 6lbs. 1oz., and consequently its specific gravity is 4,8041. It will be perceived that this is a much greater specific gravity than has ever been ascribed to the sulphate of barytes, and I regretted that I could not confirm the fact myself;—but having no opportunity of weighing this stupendous crystal hydrostatically in the museum of Mr. Hutton, I could only copy the weights from the label affixed to it. This curious specimen was found near *Cross-fell* in the county of Cumberland.

A species of this mineral is found about the Apennine mountains, and in several other parts of Italy, in round pieces about the size of a walnut, of a light gray colour and uneven surface. These have often the shining appearance of some of the other species of sulphate of barytes; and after heavy showers of rain, which wash away the earth from the mountains, they are found in abundance⁴.

These little nodules, which are called *Bologna stones*, and sometimes *Bonona stones*, are remarkable for acquiring a phosphorescent quality by calcination. Lemery relates, that this property was discovered by one Casciarolo, an Italian shoemaker, who picked up one of these stones at the foot of Mount Paderno, four Italian miles from the city of Bologna⁵.

This man, imagining from its weight and colour that it contained silver, submitted it to calcination, to extract, as he thought, the precious metal: and though he was disappointed in this respect, he discovered that the action of the fire had given it the property of being luminous in the dark; and that not only this

³ A method of analysing sulphate of barytes is described by M. Afzelius, of Upsal, in Crell's *Annales* for 1788, and in the *Annales de Chimie*, tome iii. page 290.

⁴ Busching's *Geography*, 4to, vol. iii. page 139 & 140.

⁵ See Homberg, *Philosophical Transactions*, No. 21.

particular stone, but others, which he afterwards treated in a similar manner, acquired the same property¹.

It has been said that these stones retain their luminous quality even when laid under water; that their splendour usually lasts three or four years, and that it may then be renewed by a fresh calcination².

I am not aware that the *native* sulphate of barytes is used at present for any other purpose than preparing the Bologna phosphorus, and for the extraction of pure barytes by means of charcoal and the nitrous acid. It was, however, pretty largely employed some years ago by that ornament of our country, the late Josiah Wedgwood, in the manufacture of his beautiful jasper ware, which rivalled the productions of antiquity, and found its way into the mansions of all the votaries of taste in every corner of Europe.

From this employment of the sulphate of barytes, Mr. Wedgwood, for a long time, derived great profit; none of the workmen having any idea of the nature of the material on which they were operating; until a letter, containing a bill of parcels of a quantity of the article, fell unfortunately into the hands of a faithless servant, who sold the secret, and deprived the worthy inventor for ever of that particular source of emolument. For, when the article was manufactured by those who employed inferior workmen, to whom they did not pay one-fourth of the salary which was given by Mr. Wedgwood, the price of jasper-ware became so reduced that it was no longer in Mr. Wedgwood's power to employ those exquisite modellers whom he had formerly engaged to superintend that branch of the manufacture.

The *artificial* sulphate of barytes has for many years been applied to the purposes of painting in water-colours, and it is the most delicate and perfect WHITE now in use. It was first recommended and brought forward by Mr. Hume, who has long supplied the public with it under the name of *permanent white*. I know of nothing so well calculated as this for marking bottles in a chemical laboratory, where the gases soon destroy the ink of common labels, and render them illegible. It is equally useful for marking jars, bottles, or boxes which must be kept in a damp cellar; for it is not only imperishable in such situations, but preserves its extreme whiteness, and consequently the distinctness of the characters.

Sir H. Davy says that the artificial carbonate of barytes, form-

¹ There is a paper on the preparation of the Bologna stone in the *Philosophical Collections* for 1681, published by the Royal Society of London, page 77.

² For the best method of making Bologna phosphorus, see LaGrange's *Manual of Chemistry*, vol. i. p. 188.

ed by pouring a solution of carbonate of ammonia into a solution of nitrate of barytes, also forms a pigment of a very pure white colour.

If the native sulphate of barytes, reduced to powder, be mixed with a large portion of charcoal, and submitted to a red-heat for several hours, the sulphate will at length be converted to a sulphuret of barytes, and the sulphur may afterwards be precipitated by pyroligneous or acetic acid. The acetate of barytes may then be evaporated to dryness, and a moderate heat will dissipate the acid, and leave the barytic earth nearly in a state of purity.

The following direction is given by Mons. Brisson, the French professor of chemistry. "Pulverize," says he, "sulphate of barytes, and calcine it in a crucible, with an eighth part of its weight of charcoal dust; keep the crucible at a red-heat for about an hour, and then pour the matter into water: the water will assume a yellow colour, and exhale a strong odour of sulphuretted hydrogen gas: then filter the liquor, and pour into it muriatic acid: there will be formed an abundant precipitate, which must be separated by a second filtration. The liquor that passes through the filter holds in solution muriate of barytes, which is formed by the addition of the muriatic acid. If you then add liquid carbonate of potash, the potash will combine with the muriatic acid, and the barytes with the carbonic acid, from which it may be freed in a great measure by calcination: what then remains is for the most part pure barytes."

Another process has been described by LaGrange: this consists in the mixture of muriate of lime with the barytic sulphate, which mutually decompose each other. The two salts are to be intimately mixed and fused in a crucible: the result will be sulphate of lime and muriate of barytes, which are to be separated from each other by means of water³.

Kirwan, who made many experiments on this peculiar earth, has published accurate descriptions of three distinct species of *native* barytic salts, viz. carbonate of barytes, baroselenite, or sulphate of barytes, and the liver-stone, or hepatic sulphate. The baroselenite, which we have been considering, he divides into five families, consisting of the loose, the compact, the foliated, the striated, and the acicular baroselenite⁴.

Mr. Jameson divides the barytic minerals into five species, including the sulphate and carbonate of strontian, which belong to another family, and certainly ought not to be arranged with ba-

³ For a more particular account of the process see the memoir itself, *Annales de Chimie*, tome xlvii.

⁴ See Kirwan's *Elements of Mineralogy*, vol. i. page 134—143.

rytes. The true barytic salts he divides, like Kirwan, into three species, which he calls witherite, heavy spar, and hepatite.

The first of these is the native carbonate of barytes, which will be described hereafter; the second, or heavy spar, he divides into eight subspecies, viz. the earthy, the compact, the granular, the lamellar, the fibrous, the radiated, the columnar, and the prismatic heavy spar; and the last, known to modern mineralogists by the name of hepatite, is a compound of sulphate of barytes, uncombined sulphur, and several extraneous matters, and agrees with the mineral which Kirwan has described under the name of liver-stone.

Notwithstanding this great variety of barytic minerals, for nine years after the discovery of pure barytes by Scheele, the chemists of Europe were unacquainted with any other source for the production of this alkaline earth, besides the ponderous spar of which we have been treating, until Dr. Withering, a physician of Birmingham, announced that among the minerals in Mr. Bolton's cabinet he had discovered a specimen of native carbonate of barytes, which was found in a lead-mine on Alston moor, in the county of Cumberland. This discovery was made in the year 1783, and the particulars respecting it were published in the Philosophical Transactions for the year 1784.

This mineral was first called *Witherite*, from the name of its discoverer, a gentleman well known to the literary world as the author of a useful treatise on botany, entitled "A botanical Arrangement of all the Vegetables naturally growing in Great Britain," 2 vols. 8vo; a work which has since been enlarged and much improved by Dr. Stokes, an eminent physician now living at Chesterfield in Derbyshire.

Soon after its discovery, this mineral acquired nearly as many names as those of the persons who wrote upon it, as *mephite* of barytes, *chalk* of barytes, *aërated heavy earth*, *aërated baroselenite*, *aërated ponderous spar*, &c. &c.; and then Lavoisier named it *carbonate of barytes*, which is an appropriate term, and that which it has borne ever since.

Not long after this discovery of Dr. Withering's, it was found that a similar mineral existed in abundance in the lead-mines of Anglezark in Lancashire; and while these mines were worked, the chemists of Europe might have been supplied with any quantity of this native carbonate at a small expense; and according to Leigh, who wrote the history of Lancashire, these mines abound also in sulphate of barytes¹.

Since the discovery of carbonate of barytes at Anglezark, a similar mineral of various degrees of purity has been found at

¹ Leigh's *Lancashire*, fol. Oxford, 1700. p. 71.

Aldstone in Cumberland; at Dufton and other places in the county of Durham; at Merton Fell in Westmorland; and at Snailback mine in Shropshire. I have heard that it has also been discovered in one particular district in Scotland, and also in Sweden; but Guyton and Carny in the 19th volume of the *Annales de Chimie* tell us that at that time it had not been discovered in any part of France.

Carbonate of barytes is found crystallized; and according to Thomson and Jameson, the crystals have been observed to assume four different forms, viz. double six-sided and double four-sided pyramids; six-sided columns terminated by a pyramid with the same number of faces; and small radiated crystals half an inch in length and very thin, appearing to be hexagonal prisms rounded towards the point.

The massive varieties occur in thin wedge-shaped distinct concretions, which are often very much grown together; and occasionally they pass into coarse granular masses. The crystallized carbonate of barytes is translucent, though but rarely semi-transparent. Its colours are greyish and yellowish white; also pale wine-yellow; and not unfrequently of a pale flesh-red. It slightly decrepitates before the blow-pipe, and melts readily into a white enamel. It is soluble with effervescence, in diluted muriatic or nitric acid, and may thus be distinguished from sulphate of barytes, which is insoluble in both these acids. Its specific gravity is 4.33; though when prepared artificially it scarcely exceeds 3.76. It has no sensible taste, and yet it is an active poison. It is very sparingly soluble either in cold or hot water; and is not altered by exposure to the air. By peculiar management it may be decomposed when submitted to an intense heat.

The native carbonate of barytes found at Anglezark consists of 22 parts of carbonic acid, and 78 of barytes; and the factitious carbonate is a similar compound. Pelletier says that he analysed some native carbonate, and found it composed of 22 parts of carbonic acid, 62 parts of barytes, and 16 parts of water; but I apprehend this account is erroneous.

Those who have done most in investigating the nature of this earth, since the discovery by Dr. Withering, are Pelletier above mentioned, Vauquelin, and Fourcroy in France; and Professor Hope of Edinburgh. The French chemists published an account of their experiments in the *Annales de Chimie* for the year 1797; but Dr. Hope had published his valuable paper in the *Edinburgh Transactions* four years before this². It is, however, generally acknowledged that, before these eminent chemists undertook the

² See *Annales de Chimie*, tom. iv. page 62; tom. xxi. pages 113 and 276; and the *Edinburgh Transactions*, vol. iv. p. 36.

series of experiments in which each of them was engaged, pure barytes was not known.

At one time no carbonate of barytes was found any where in these kingdoms, except in the lead-mines of Anglezark in the hundred of Salford in the county of Lancaster. Conceiving that this mineral product might probably be usefully employed in some of our manufactures, if an abundant supply could be procured, I determined to go to the mines to make the necessary inquiries; which I did in the autumn of 1810.

On inquiring at Chorley, I found that the mines are in the midst of the moors, at a considerable distance from any turn-pike road, about eight or nine miles from the town of Bolton, and three from Chorley; and in so obscure a part of the country that it would be necessary for me to take a guide with me; and I was so fortunate as to meet with a gentleman in the town, who very kindly offered to accompany me and conduct me thither.

From the town of Chorley you go about a mile on the road to Bolton, and then turning off to the right, proceed through a very rough stony lane, which brings you near to the village of Limbrick, which is about two miles from Chorley; and then passing over some romantic fields, you arrive at the house of Banister Derbyshire, a fine old man of seventy years of age, who occupies the estate in which the mine is situated.

This man, who knows more of the history of these singular mines than any one in the neighbourhood, walked with us to the spot, and showed us the places which were formerly occupied for the different purposes connected with the working of the mines.

From him I learnt that all these are *lead-mines*, which were in full work more than a hundred years ago: and that they were again opened, long before his time, by Sir Thomas Standish, the father of the present proprietor.

From the appearance of the land, it is evident that there have formerly been a great number of shafts for drawing up the minerals; and on making inquiry as to this point, our guide informed me that he was sure he could find forty at the least; whence I conclude that a large quantity of lead ore must some time or other have been raised.

About forty years ago these mines were worked a third time by the direction of Sir Frank Standish, who drove fresh levels from the foot of the several hills, into the heart of the mine, in order to carry off the water, and enable the men to work: but having engaged several different sets of workmen, who all conspired to defraud him of their time, and endeavoured to impress his mind with an idea of the small quantity of ore that could be procured, at the moment when they were practising various arts

to induce him to lease the mine to them, he became tired of mining; and about the year 1790, when he had sunk some thousands of pounds in the undertaking, the work was again discontinued, and all the miners dismissed.

It is apparent that this proprietor had no idea of working these mines again, for every thing about them has been allowed to go to ruin. Our guide showed us where stood the large water-wheel for winding up the water from those parts of the mine that could not be drained by the levels; which was the site of the warehouse for storing the washed ore; and where stood the smithy for repairing the tools of the workmen: but there is now scarcely a square yard of walling belonging to any of these buildings left standing entire.

Knowing that we are all the victims of habit and the creatures of circumstance, I could not help fancying, while exploring this forsaken domain, what a different character the proprietor of these mines might have been, had he been fortunate enough in his youth to receive a liberal education, and to imbibe a taste for literature and science: for, had this been the case, he might have been as eminent for the accurate investigation of the treasures which nature has hidden within his most valuable estate, and for other useful and scientific pursuits, as he was, through a long life, for his skill on the turf at Newmarket.

The quantity of carbonate of barytes in these mines is immense, much greater, I understand, than that of the lead ore (five to one, as our guide supposed); but as the metallic ore was raised, this was always left behind in the mine, being considered of no value. The workmen called it spar.

Some of the best-informed people in the town of Chorley say, that the first time any idea was given of the value of this spar, was by the arrival of two Frenchmen about the year 1782. It seems that they were in the town some days without the nature of their business being suspected, till it was at last discovered that they had been at the lead-mines, and had filled two boxes with the spar, which they secured with great care, and sent off by the carrier before they left the town.

At this, Mr. Tatham, the steward of Sir Frank Standish, immediately took an alarm; and having given strict orders that in future no one should be suffered to take away any of the spar, set himself to make every inquiry he could into its nature; to learn, if possible, to what uses these foreigners intended putting it; and whether some methods might not be discovered for consuming it in this country. In prosecuting these objects of inquiry, however, he never succeeded.

The papers by Dr. Withering in the Philosophical Transac-

tions, on the carbonate of barytes, and Dr. Crawford's on the muriate of this earth, had now drawn the attention of all the chemists of Europe to this newly discovered mineral; so that its real nature and properties were every where soon understood. But during this investigation, in which every chemist who was fortunate enough to procure specimens was probably engaged, nothing new occurred at the mine or in the neighbourhood respecting it, till it was discovered that a man of the name of Smithels, who occupied a cottage and about forty acres of land under Sir Frank Standish, close to the mines, had long been engaged in disposing of the carbonate of barytes in an illicit manner.

This man, who was well known in the neighbourhood of Chorley, and is still remembered by many of its inhabitants, used to get the spar from among the heaps of stone and rubbish that lie round the mouths of the old shafts. This he used to pack in strong boxes, and delivered them himself, by his own cart, to the carrier in Chorley, to be conveyed to Liverpool.

He managed this business so well, that he not only bought the boards for making the boxes, but prepared the boxes himself in the night, and suffered no one to see him pack the article, or carry it away when packed. Besides, it went from Chorley by the common carrier to a broker in Liverpool, who shipped it to a middle-man upon the continent;—so that the place where it was actually consumed could never be traced out.

A neighbouring farmer had, indeed, for some years observed that James Smithels was often engaged in picking something from off the waste land; and that often on moonshine nights, when they imagined no one observed them, he and his wife were employed for hours together upon the mounds which stand round the old shafts; and on the circumstance being mentioned to the steward of Sir Frank Standish, he put an entire stop to this poor man's little trade.

However, when he was questioned by the steward, and by a variety of other persons, respecting this transaction, he remained sullen and silent, and would never give them the least information as to the quantity he had sold, the price he had obtained for it, or even to what part of the world it went. It was, however, imagined, that the two foreigners before mentioned were the people who had engaged this man to collect it, and that they had found some means of regularly paying him for what he procured for them.

As the quantity of carbonate of barytes thus collected, was much larger than could be employed merely for the preparation of chemical tests, and for a few common purposes of philosophical research, I was desirous of ascertaining something more,

if possible, respecting this traffic in the Anglezark spar; and from one Alexander Gerrard¹, an intelligent farmer, who resides not far from the mine, and was formerly very intimate with the aforesaid James Smithels, I learnt the following particulars:

That Smithels, only a short time before his death, informed Gerrard that, in the whole, he had sold a very large quantity of the spar; that he received five guineas per ton for it; that it went from Liverpool to some part of Germany; and that he had understood, from the person who usually paid him, that it was consumed in some process in the manufacture of porcelain².

Being desirous of knowing whether these poor uneducated men had any idea of the nature and properties of the carbonate of barytes, I put some questions to them for that purpose. They told me, all they knew of it was, that it was a strong poison.

When I endeavoured to ascertain the extent of their knowledge on this subject, Mr. Derbyshire assured me that some years ago, he lost some cows, who had strayed from their pasture, and were found licking the lumps of spar which at that time lay about the mine in abundance; and that on opening one of these animals, several small pieces of spar were found in its stomach.

He told me also, that it was impossible to keep any fowl upon the farm; for, mistaking the smaller pieces of the spar for white sand, they were sure to pick it up, and die immediately. Ducks and geese, he says, he can keep, as they do not swallow it, except at the time they lay their eggs, and then they never fail to take it, and with the same baneful effect. Doubtless they mistake it for lime or chalk, which all oviparous animals are obliged to swallow at the time of their laying, in order to shell their eggs. For if fowls be pent up in a situation where they are deprived of all calcareous matter, it is well known that they lay their eggs without shells.

It has been doubted whether the carbonate of barytes be a poison to the human species; but on examining Leigh's History of Lancashire, written more than a century ago, to see if these mines were noticed by him, I find the question answered in the affirmative³.

Mons. Fourcroy, when examining the question, whether the

¹ I have entered upon this detail, and given the names of these men, in order that, if any persons should wish to prosecute the inquiry, they may know to whom to apply for information.

² This circumstance has induced me to write so full an account of this transaction, in the hope that some of our manufacturers of earthenware will be tempted to persevere with experiments on the native carbonate of barytes, till they discover an advantageous method of employing this mineral in some branch of their manufactory.

³ Leigh's *Natural History of Lancashire*, folio, Oxford, 1700, page 70.

carbonate of barytes be a poison, or not, says, "There is every reason to believe that pure barytes is a violent poison, since when combined with the carbonic acid, and having lost all its acrid taste by this union, it speedily poisons animals. Mammiferous animals which have been made to take it, have experienced acute pains, convulsions, vomiting, and death. Their stomach and intestines were inflamed, spotted, sphacelous, and even, as it were, in some parts corroded: its administration in medicine must, therefore, require great caution¹."

"Messieurs Huzard and Biron gave to some horses the muriate and carbonate of barytes, in doses of 118 grains English, every day; and these animals died suddenly after having taken them for a few days." "A dog, which Pelletier caused to swallow 20 grains, was seized with vomiting, and died within eight hours afterwards²."

In consequence of the various accidents which occurred in Lancashire after the opening of the Anglezark mines, this spar in the district where the mines are situated, has obtained the name of *rats-stone*.

Pelletier relates, that the Society of Health at Paris was engaged in ascertaining what advantages medicine might derive from the use of barytes; and that both the muriate and carbonate of this earth were given to horses seized with that highly infectious disease called the *farcy*, for which corrosive sublimate is generally administered; and he adds, that both these medicines given to two different horses, in the quantity of two drachms a day, seemed for a while to have effected such a change that they were even considered as cured at the end of a fortnight, but nevertheless they both died within a few days of each other³.

Dr. Withering observed the difficulty there is in decomposing the native carbonate of barytes, and that when submitted to a strong heat it sooner fuses than parts with its carbonic acid. But Dr. Hope announced⁴, that when he submitted it to an intense heat in a black-lead crucible, the carbonic acid was separated, though in an earthen crucible nothing was permitted to escape, and consequently no decomposition was effected. In considering this result, Pelletier was induced to try the effect of mixing it

¹ Fourcroy's *General System of Chemistry*, vol. ii. p. 273.

² Chaptal's *Chemistry applied to the Arts*, vol. ii. page 70. Nicholson's *Journal*, 4to, vol. i. page 529.

³ *Annales de Chimie*, tom. xxi. page 113, or Nicholson's *Journal*, 4to, vol. i. page 529.

⁴ Dr. Hope published his experiments in the year 1793, in the *Edinburgh Transactions*, vol. iv. page 36.

with charcoal before he heated it, and by this means he obtained barytes tolerably pure and soluble.

M. Fourcroy, who has related this circumstance, 'confesses that the theory of the experiment is unknown to him'⁵; but may it not be attributed to the charcoal combining with the carbonic acid of the carbonate of barytes, and with it forming carbonic oxide⁶, which is a gas somewhat lighter than atmospheric air, and very highly combustible?

If, however, barytes perfectly pure be required, it can only be obtained by dissolving the native carbonate, or the artificial sulphuret of barytes procured according to the directions given at page 125, in diluted nitric acid; in evaporating the solution either to dryness, or the point of crystallization, and then decomposing this salt by heat. The process in detail may be thus described:

The mineral (the sulphate or the carbonate) is first to be reduced to powder, and intimately mixed with about one-fourth of its weight of ground charcoal. It is then to be put into a crucible and submitted for an hour to the action of a red heat, well covered with charcoal to secure it from the access of atmospheric air. This treatment, if the sulphate be operated upon, will convert the sulphate of barytes to a sulphuret, which is to be dissolved in water and the impurities suffered to subside. The clear solution is then to be treated with nitric acid, which will combine with the barytes and occasion the sulphur to precipitate. The newly formed nitrate of barytes is now to be slowly evaporated, until the salt crystallizes; and then, if the salt be exposed in a crucible to a gradual heat, to separate the remaining water, and afterwards to a stronger heat, sufficient to expel the whole of the nitric acid, pure barytes will remain, which should be quickly removed to a stoppered bottle to prevent its absorption of carbonic acid.

BARYTES is an oxide of barium, and possesses the following properties:—When pure, it is of a greyish white colour, and is so porous that it may very readily be reduced to powder. It consists of 1 proportional of barium = 70 + 1 proportional of oxygen = 8, and consequently in the table of equivalents is represented by 78. Its specific gravity is about 4. When exposed to the air, it changes rapidly; it swells like quicklime, and, like it, falls into a white powder; but this slacking is much more violent and speedy than that of lime. In this process it combines so intimately with the water of the atmosphere, which it

⁵ Fourcroy's *System of Chemistry*, vol. iv. page 14.

⁶ Carbonic acid contains scarcely 27.3 per cent. of carbon; but carbonic oxide contains nearly 43 per cent.

solidifies, that it will not part with it even at a red-heat. In this state it is called the hydrate of barytes, and consists of 1 proportional of barytes = 78 + 1 proportional of water = 9: consequently we say the hydrate of barytes is represented by 87.

If the hydrate of barytes be dissolved in boiling water, and the solution suffered to cool, crystals containing a still larger proportion of water will be deposited. These crystals, white and transparent, generally appear in the form of hexagonal prisms, considerably flattened, and have been found to consist of 1 proportional of barytes = 78 and 20 proportionals of water = 9×20 or 180 water; so that the crystallized hydrate must be represented by 258.

These crystals are sometimes long four-sided prisms, terminated at each extremity with a four-sided pyramid. Sometimes they are attached to each other in a peculiar way, and sometimes the crystallized salt precipitates in the liquor in the form of cubes. The crystals of barytes require more than 17 times their weight of water for solution. According to Mr. Dalton, if these crystals be exposed to the air, they will effloresce and fall into a white powder, consisting of 1 proportional of barytes and 5 proportionals of water. Hence it seems that there are at least three distinct hydrates of this earth: viz.

1st hydrate consisting of	78 barytes + 9 water = 87
2nd hydrate	78 barytes + 45 water = 123
3rd hydrate	78 barytes + 180 water = 258

Barytes has, however, several other properties which must be enumerated. It has a harsh and pungent taste, and is more caustic than quicklime; it has no smell whatever, but when taken into the stomach acts as a most corrosive poison. It is very difficult of fusion, but when strongly heated on charcoal before the blow-pipe, it melts into a grey opaque mass. Like the alkalies, it changes the vegetable blues to a deep green; the red to a violet or blue; and the yellow vegetable colours, such as turmeric, &c. to a brown. It is also similar to the alkalies in being itself a metallic oxide; in its rendering oils miscible with water; in forming glass when fused with silica; in its solubility in water; and in its capability of dissolving some of the other metallic oxides.

It is soluble in about 20 parts of water at the temperature of 60° ; but boiling water will dissolve half its weight of this earth, part of which, as has been already mentioned, will crystallize on cooling. It absorbs carbonic acid from the atmosphere, and has so strong an affinity for sulphuric acid, that it will not part with it even to pure alkalies. Hence it has the property of decomposing sulphate of potash, or sulphate of soda. Barytes is unalterable by light: it is a non-conductor of electricity; and when dissolved in water, or in certain acids, furnishes excellent tests

for chemical analysis. It is also capable of making a very tenacious cement. When strongly heated in oxygen gas, or if oxygen gas be passed over red-hot barytes, the oxygen will be absorbed, and the barytes will be converted to a grey substance, which may be called the *peroxide of barium*, consisting of barium 70 and oxygen 16 = 86; or it may be stated thus: barytes 1 proportional = 78 + 1 additional proportional of oxygen 8 = 86. Barytes may be known from all the other earths, by its superior solubility in water; by its forming an insoluble compound with sulphuric acid; and by its imparting to flame a yellow colour.

When speaking of the native carbonate of barytes, I should have remarked, that neither nitric nor muriatic acid, when concentrated, has any effect in dissolving carbonate of barytes, as was first shown by Fourcroy¹. This chemist was, however, mistaken in asserting that barytes "forms with *all* the acids the most permanent compounds, and the most difficult of all to be decomposed," since it is true only of those acids which form with barytes *insoluble* salts; for, if this earth be employed to decompose common salt, it only produces a partial decomposition, and may be precipitated again from the acid, by means of either of the carbonated fixed alkalies².

It has already been observed that the chief use which has hitherto been made of barytes, has been in the preparation of certain tests for chemical analysis; and as these are of the utmost importance to every analytical chemist, I shall now proceed to give an account of the methods of preparing some of the most valuable of these tests. Those in common use are, the nitrate, the muriate, and the acetate of barytes; and not unfrequently a solution of pure barytes in distilled water.

By copying the particulars of a few of these processes from my common-place-book, where they stand as they were entered at the time of making the experiments, I shall be in no danger of misleading the reader. For making nitrate of barytes I first diluted 2lbs. of nitric acid, sp. gr. 1.250, with 8lbs. of distilled water.

When cold, the mixture had the specific gravity of 1.0528.

To this diluted acid one pound of the native carbonate of barytes was added, and the whole submitted to a gentle heat. The acid dissolved the barytes with rapidity; but when the action had ceased, a large portion of residuum, which was chiefly nitrate of barytes in a crystallized state, was found in the vessel wherein the solution had been made. To dissolve this nitric salt more water was added by degrees, until sixteen pounds were employed; when the only residuum remaining was one ounce of

¹ *Annales de Chimie*, tom. iv. page 62.

² *Ibid.* tom. xlix. page 95. Nicholson's *Journal*, vol. xviii. page 68.

the carbonate of barytes, which the nitric acid was incapable of taking up¹. The materials used then were 2lbs. of nitric acid, sp. gr. 1.250, 24lbs. of water, carbonate of barytes 15oz., making together 26lbs. 15oz., which produced 22lbs. 6oz., sol. nitrate of barytes, sp. gr. 1.0507, leaving a loss of 4lbs. 9oz., arising from evaporation and disengagement of carbonic acid.

Finding that so large a portion of water is necessary for holding the nitrate of barytes in solution, I have since diluted the 2lbs. of nitric acid, sp. gr. 1.250, with 24lbs. of pure water.

When cold, the mixture had the specific gravity of 1.0156.

To this diluted acid I added 19oz. of the native carbonate of barytes; and though the acid was so very much diluted, it immediately acted upon the earth and dissolved it rapidly, even in the cold. When submitted to a gentle heat, the solution went on with still greater rapidity, and in about an hour the whole was dissolved. The produce was 22lbs. 14oz. sol. nitrate of barytes, sp. gr. 1.0600, leaving a loss by evaporation and the disengagement of carbonic acid of 4lbs. 5oz.

It will be observed that there is not only less trouble, but an economy, in thus diluting the acid, as it prevents in some measure the loss of a part of the acid in consequence of too rapid an action. To obtain the nitrate of barytes in a state of purity, the solution should be evaporated to dryness, and the dry salt redissolved and crystallized. The crystals are permanent octahedrons, which sometimes adhere to each other in the form of stars. At other times the crystals are obtained in small plates², whose specific gravity is 2.9149. The taste of this salt is hot and astringent. It is soluble in twelve parts of water at 60° and in four parts of boiling water. When submitted to a red heat, the whole of the acid flies off, and pure barytes remains in the crucible. The nitrate of barytes is a very convenient test for many purposes, and especially for detecting the adulteration of nitric acid by the addition of sulphuric acid: but in this case it is absolutely necessary to dilute the suspected nitric acid very considerably with distilled water previously to the application of the test; otherwise, a portion of the barytic salt is apt to precipitate, merely in consequence of the nitric acid abstracting part of the water which held it in solution, and this will occasion deception.

The dry salt consists of 1 proportional of barytes 78 + nitric acid 54 = 132. The proportions per cent. are, barytes 59,

¹ Some years ago Mr. Hume noticed that the nitrate and the muriate of barytes are entirely *insoluble* in the respective acids of which they are formed. This, however, is not the case with the sulphate of barytes, for that salt is perfectly *soluble* in its own acid. *Phil. Mag.*

² Hassenfratz *Annales de Chimie*, xxviii. 12.

nitric acid 41. The crystals consist of 1 proportional of dry nitrate 132 + 2 proportionals of water 18; or per cent, nitrate of barytes 88 + water 12.

In preparing the muriate of barytes, I have generally used very weak muriatic acid of the specific gravity of 1.0612. Such acid may be formed by mixing muriatic acid at 1.170 with double its weight of pure water. In this menstruum I dissolve the native carbonate of barytes to the point of saturation. Twenty-four pounds of this diluted acid are capable of dissolving exactly six pounds and a half of the native mineral; and the solution of the muriate of barytes which results from the process will be of the specific gravity of 1.260.

It did not occur to me, or I would have mentioned in an earlier part of this essay, that in calculating the equivalent numbers of bodies, it is most convenient to make hydrogen, which is the lightest substance we know of, *unity*, and oxygen 8, because oxygen unites with hydrogen in the proportion of eight of oxygen to one of hydrogen, to form water. The equivalent numbers throughout these volumes are all deduced from this basis.

The muriate of barytes, or chloride of barium, in a state of dryness is composed of 1 proportional of barium 70 + 36 chlorine = 106, or, barium 66 + 34, chlorine = 100.

This salt commonly crystallizes in tables; but according to Dr. Crawford it sometimes appears in the form of two eight-sided pyramids applied base to base. It is unalterable in the air, and not decomposable by heat³.

The poisonous nature of barytes, in which it differs from all other earths, has been mentioned; but its most distinguishable property is the facility of its crystallization when dissolved in water, and which decidedly marks it to be very different from lime, which is sparingly soluble in water, and does not form crystals when it separates itself therefrom.

At one time strontites was confounded with barytes, and many chemists were at a loss to know whether there was any real difference between the two minerals; but an important series of experiments made by Pelletier, in the year 1796, has put this matter beyond all doubt, and established them as two distinct substances⁴.

There are certainly many points of resemblance between

³ Dr. Crawford has expressly written on the properties of the muriate of barytes. His paper is in the second volume of the *London Medical Communications*, page 301.

⁴ The paper which gave an account of these experiments was read before the National Institute, April 30th, 1796; and afterwards published in *Annales de Chimie*, tome xxi. page 113, &c. A translation of it may be seen in Nicholson's *Journal*, 4to, vol. i. page 518.

barytes and strontites, such as their being both found native, and only in the state of combination with sulphuric and carbonic acids,—these native productions are also decomposable by similar means,—both sulphates are nearly insoluble in water, and yet soluble in an excess of sulphuric acid,—both carbonates are soluble in diluted muriatic or diluted nitrous acid, and neither of them is precipitated by pure ammonia.

There are, however, so many differences, and those so distinctly marked, that no chemist can now easily mistake the one earth for the other. The mention of a few particulars will be sufficient. Strontites has less attraction for acids than barytes; hence the salts of strontites are decomposable by barytes: strontites requires much more of any acid for its saturation than barytes does; the salts formed by the two earths are different in form and in the rate of their solubility in water: for instance, muriate of barytes, as has been already mentioned, crystallizes in plates; whereas muriate of strontites gives slender hexagonal prisms. Moreover, pure barytic earth does not require one-tenth of the quantity of water for its solution that strontites does; and lastly, if strontites, or the salts formed with it, be dissolved in or mixed with alcohol, the spirit will burn with a flame of the colour of *carmine*; whereas barytes, as has been noticed already, gives a bright *yellow* colour to flame.

Water at the temperature of 50° takes up about a twenty-fifth part of its weight of barytes in its caustic or pure state; the solution remains transparent and colourless, and is known in the laboratory of the chemist by the term *barytic water*. It is necessary to keep it in bottles well closed, otherwise the earth will acquire carbonic acid from the atmosphere, and separate itself from the water of solution, as lime does in similar circumstances.

The best method of preserving barytes in a state of purity, is to dissolve it in warm distilled water; and if, during the heat that is generated by the slacking of the earth, the water be saturated with it, an abundance of crystals will be procured when the whole has become cold. These crystals should be kept in well stopped bottles, for the purpose of making barytic water as it may be required. It is extremely useful as a chemical reagent for discovering the presence of sulphuric acid, and for other purposes.

An Acetate of barytes has also been found to be a convenient preparation of this valuable earth. This may be readily made by dissolving the native carbonate to saturation in acetic acid, when, by spontaneous evaporation, the solution will deposit very beautiful prismatic crystals of acetate of barytes, which will not deliquesce in the atmosphere.

When I first made acetate of barytes in quantity, I proceeded thus:—To twelve pounds of acetic acid of the specific gravity of 1.0420 I added three pounds of the native carbonate of barytes, and submitted the vessel containing it to a gentle heat. I found that, to dissolve the carbonate of barytes in acetic acid, it is only requisite to have the acid a little warm; 90° of Fahrenheit will be quite sufficient, until the acid approaches the point of saturation, and then it will be advisable to give it the heat of 130° .

When the action had ceased, and the whole become cold, I poured the solution from the residuum, and found a large portion of crystals of acetate of barytes among the carbonate which remained undissolved. Two pounds of water, however, were found sufficient to dissolve these crystals; and when the whole of the solution was filtrated, and the residuum carefully dried, twelve ounces of the original carbonate of barytes remained; so that the materials used and the produce obtained stood thus: acetic acid, specific gravity 1.0420, 12lbs. Water 2lbs., and carbonate of barytes $2\frac{1}{4}$ lbs. produced 13lbs. of sol. acet. barytes, specific gravity 1.1870, leaving loss by evaporation, &c. $3\frac{1}{4}$ lbs.

If the two pounds of water had been added to the acetic acid in the first instance, the specific gravity of the mixture would have been 1.0380.

Finding that the acid which I employed was capable of dissolving more barytes than it could afterwards hold in solution, I have since adopted the following process, which I recommend as the best that I have been able to discover for making the acetate of this earth. Take acetic acid, specific gravity 1.0420, 12lbs, pure water 12lbs, and native carbonate well washed, $2\frac{1}{2}$ lbs. The produce will be, sol. acet. baryt. 1.1480, 21lbs, leaving a loss of $5\frac{1}{2}$ lbs.

The specific gravity of equal weights of acetic acid and water, when mixed, will be 1.0260; therefore acetic acid, which may originally be of a strength about equal to this specific gravity, will be very proper for the process.

The acetate of barytes has a sour and rather a bitter taste; it is soluble in water, and effloresces in the atmosphere. Its specific gravity is 1.8. It is decomposable by the fixed alkalies, which seize the acetic acid and precipitate the barytes. Most of the soluble sulphates also decompose it; and on this account it is constantly employed to detect sulphuric acid, or the sulphuric salts in solution. One hundred parts of water at the temperature of 60° dissolve 88 parts of the salt; boiling water dissolves nearly its own weight. It is composed of barytes 78 + acetic acid 58 = 128; or barytes 61.06 + acetic acid 39 = 100.

Whether the barytic salts are used in medicine, or as chemical

reagents, it is of the utmost consequence to have them made uniformly the same. I have therefore thought it worth while to give these experiments in detail, in order to furnish, by means of the specific gravity, a standard for each of these solutions; so that those who may have occasion to employ the nitrate, the acetate, or the muriate of barytes, may know how to procure a solution that will always contain the same proportion of barytic earth.

The other salts that have been formed with barytes are the following, which I have arranged alphabetically, for the sake of greater facility of reference.

Antimoniate of barytes. This is a white powder, which may be obtained by mixing muriate of barytes with antimoniate of potash. It is perfectly insoluble in water. It is a light flocculent precipitate, which does not adhere to the sides of the vessel. It is not decomposed by exposure to the air, but the nitric acid extracts by digestion all the barytes¹. It is probably composed of one atom barytes, and one of antimonious acid.

Antimonite of barytes. If a boiling solution of antimonite of potash be let fall drop by drop into a boiling solution of muriate of barytes, the antimonite of barytes crystallizes gradually on the tube in the form of small white needles of a silky brilliancy. These are slightly soluble in water, and unalterable in the air². The salt consists of one atom barytes and one of antimonous acid.

Arseniate of barytes may be formed by mixing arseniate of potash with muriate of barytes, which produces an insoluble arseniate of this earth. It is in the form of a white powder, which is not decomposable by heat. It was first formed by Scheele, by dissolving pure barytes in arsenic acid³. Supposing this salt to be a compound of 1 atom of barytes and 1 atom of arsenic acid, its equivalent numbers will be, barytes 78 + arsenic acid 62 = 140.

Arsenite of barytes is formed, like the foregoing, with arsenious acid. It is a white insoluble powder⁴, composed of one proportional of barytes 78 + 1 of arsenious acid 54 = 132.

Benzoate of barytes is soluble in water, and crystallizable. It may be decomposed by heat, but is unalterable in the air. It is a compound of barytes 78 + benzoic acid 120 = 198.

Boletate of barytes. This salt contains an excess of acid,

¹ Berzelius in *Nicholson's Journal*, vol. xxxv. page 40.

² *Ibid.* page 45.

³ Laugier, *Annales de Chimie*, tom. lxxxv. page 58.

⁴ *Ibid.*

crystallizes in white plates, and is but little soluble in water, or even in nitric acid. When thrown on a plate of red-hot iron, it burns with a red flame and remarkable scintillation, leaving carbonate of barytes as a residuum⁵. Braconnot in the year 1811 discovered the boletic acid, and to that chemist we are indebted for the chief of what we know respecting the salts which have been formed by its means⁶. The acid is procured from a species of agaric, the *Boletus igniarius* of Linnæus, a fungus so called in consequence of its being frequently used for the purpose of tinder. The boletate of barytes is probably composed of one atom of barytes and one of boletic acid.

Borate of barytes is a white powder insoluble in water. It is prepared in a way similar to that of the other earthy boracic salts. It is a compound of 78 barytes + 22 boracic acid = 100.

Camphorate of barytes may be prepared by mixing camphoric acid with a solution of pure barytes, and boiling the mixed solution to the point of crystallization. When the evaporation is conducted slowly, the salt is deposited in thin lamellar crystals, which appear transparent while immersed in the liquor, but become opaque when exposed to the air. The salt has but little taste, though it leaves at last upon the tongue a slight impression of acidity mixed with bitterness. When exposed to heat it melts easily, and the camphoric acid is volatilized. When the heat is considerable, the acid burns with a lively blue flame, which becomes afterwards red, and at last white⁷.

Carbonate of barytes. The artificial carbonate is similar in its nature to the carbonate which is found native, and has already been described at large, page 126—133. It is a compound of 78 parts of barytes + 22 parts of carbonic acid = 100.

Chlorate of barytes may be formed by passing chlorine gas into a solution of pure barytes. The salt crystallizes in quadrangular prisms, and is soluble in about four times its weight of water, at the temperature of 60°. The discoverer of chloric acid, M. Gay Lussac, first procured it from this salt by acting upon it with sulphuric acid. It is a compound of one proportional of barytes 78 + one of chloric acid 76 = 154.

Chromate of barytes may be formed by adding chromate of potash to a solution of muriate of barytes. It is a yellow insoluble powder. Vauquelin has written the most on the chromates, in an essay printed in the 70th volume of the *Annales de Chimie*. According to him the salt consists of 62.2 barytes + 37.4 chromic acid = 99.6.

⁵ Thomson's *System of Chemistry*, ii. p. 480.

⁶ *Annales de Chimie*, lxxx. 279.

⁷ Bouillon Lagrange, *Annales de Chimie*, xxvii. page 28. Thomson's *System*, ii. page 480.

Citrate of barytes. When barytes is added to a solution of citric acid, a flaky precipitate appears, which is at first dissolved by agitation, but remains permanent when the saturation is complete. The citrate of barytes thus formed, is precipitated in the state of a white powder, but it gradually assumes the appearance of silky flakes, or forms a kind of vegetation very brilliant and beautiful. It requires a great quantity of water to dissolve it. According to Vauquelin it is composed of 50 of the crystallized acid and 50 of barytes, which is nearly equivalent to one proportional of the earth $78 + 58 \text{ acid} = 136$.

Fluate of barytes, or according to Dr. Thomson fluoride of barium, is in the form of white flocks, insoluble in water, but soluble in an excess of fluoric acid. It is composed of fluorine 16, barium 70.

Formate of barytes. This salt is obtained in permanent crystals, unalterable by exposure to the air. According to Dr. Thomson, they contain no water of crystallization, and are composed of formic acid $32.1 + \text{barytes } 67.9 = 100$.

Gallate of barytes is a salt of little solubility; it is of a fawn colour, and dissolves more abundantly in water when mixed with an excess of base, than otherwise¹. This salt may be considered to be a compound of one proportional of barytes $78 +$ one of gallic acid $63 = 141$.

Hydriodate of barytes. This salt crystallizes in fine prisms similar in appearance to muriate of strontites. It is very soluble in water. By a red heat this salt is converted into iodide of barium. Gay Lussac. Thomson's *System of Chemistry*. Its composition may be considered to be barytes $78 +$ hydriodic acid $126 = 204$.

Iodate of barytes. This salt may be formed by treating carbonate of barytes with iodic acid. It appears in a kind of farinaceous powder, and is very insoluble in water. Its constituents are, barytes $78 +$ iodic acid $165 = 243$. This has sometimes been called *oxiodate* of barytes.

Malate of barytes. This salt is somewhat similar in its properties to malate of lime. It has an acid taste, and consists of one proportional of barytes $78 +$ one of malic acid $70 = 148$.

Molybdate of barytes. This salt, like the other salts of barytes, is formed of one proportional of barytes $78 +$ one of molybdic acid $72 = 150$. Its properties are unknown.

Oxalate of barytes. This salt may be formed by adding a solution of oxalic acid to a solution of pure barytes. It first precipitates in the state of a white powder, but becomes dissolved by the addition of oxalic acid, which produces needle-formed crystals of

¹ Fourcroy, vol. vii. page 248.

super-oxalate of barytes. The oxalate of barytes is nearly insoluble in water. It is composed of one proportional of barytes 78 + one of oxalic acid 36 = 114.

Phosphate of barytes may be formed by adding a solution of phosphate of soda to one of muriate of barytes. It appears in the state of a tasteless white powder insoluble in water. It consists of barytes 78 + phosphoric acid 28 = 106.

Phosphite of barytes. Berzelius prepared this salt by pouring muriate of barytes into a solution of phosphite of ammonia. No precipitate appeared at first, but in twenty-four hours the glass was covered with a crust of phosphite of barytes². When washed and dried, its composition was, in 100 parts, phosphorous acid 24.31, barytes, 67.24, water, 8.45.

Seleniate of barytes. Seleniate of barytes is insoluble in water, and can only be obtained in a white powder, but the biseleniate is soluble. The former Dr. Thomson supposes to consist of one proportional of selenic acid 56 + one of barytes 78 = 134.

Silicate of barytes. This salt is formed by the mixture of an aqueous solution of barytes with a solution of silicate of potash. The product is a silicate of barytes in white powder. The proportions of the constituent parts of this salt are not known.

Succinate of barytes. This salt was formed by Bergman, by dropping succinate of ammonia into muriate of barytes. In this process the salt partly precipitates, and is partly deposited in small crystals on the sides of the vessel. Bergman: Thomson. According to the above principle, this salt must be formed with one proportional of barytes 78 + one of succinic acid 50 = 128.

Tartrate of barytes is a salt sparingly soluble in water, is tasteless and does not redden vegetable blues. It is decomposable by oxalic acid. It is a compound of one proportional of tartaric acid 67 + one of barytes 78 = 145.

Tungstate of barytes is in the form of a white powder, which is insoluble in water. Its composition and properties are unknown.

Urate of barytes. This is a white powder in some respects resembling uric acid. Taking 46 for the equivalent number of uric acid, the composition of this salt will be one proportional of barytes 78 + one of uric acid 46 = 124.

Zumate of barytes is an incrySTALLIZABLE salt, having the appearance of gum. This salt, as appears by the name, is a compound of barytes and zumic acid. This peculiar acid was first procured by Braconnot from a preparation of fermented rice. It was named by Dr. Thomson zumic acid, from a Greek word signifying *leaven*. The properties of zumate of barytes are as yet but little known.

² Thomson; Berzelius, *Annales de Chim. et Phys.* ii. 231.

Barytes will also combine with sulphur and phosphorus, and with some of the earths.

Sulphuret of barytes, as we have already shown at page 133, may be formed by heating to redness in a crucible a mixture of the native sulphate of barytes and charcoal, both in fine powder. The sulphuret of barytes, which results is of a reddish yellow colour, and is composed of barium 70 + sulphur 16 = 86. When put into hot water, it decomposes the water, and two new compounds are formed, viz. hydrosulphuret of barytes, and hydroguretted sulphuret of barytes. The first appears in the form of crystals, while the hydroguret remains in solution.

Phosphuret of barytes may be prepared by passing phosphorus over heated barytes, or by exposing a mixture of barytes and phosphorus in a glass tube to a heat sufficient to produce the combination. It has the property of decomposing water, and from that decomposition phosphuretted hydrogen gas is evolved, which rises in bubbles to the surface of the water, and inflames as it comes in contact with atmospheric air.

Phosphuret of barium is composed of barium 70 + phosphorus 12 = 82.

Such are the principal salts, &c. which have hitherto been made by means of barytes: the nature of the earth, and its uses in a separate state, remain to be spoken of hereafter.

When the peculiar properties and the decided characteristics of barytes became known, some persons suspected that it was a metallic oxide, and the usual methods were resorted to for its reduction. That it is the oxide of a metal very difficult to be reduced, was the opinion of Bergman and Lavoisier; but it was reserved for Davy to demonstrate and establish the truth of this conjecture. The detail of the experiments by which he separated the metallic substance, which is the base of barytes, may be seen in the *Philos. Trans.* for 1810, page 63.

To those persons who have not the opportunity of referring to the *Transactions of the Royal Society*, the following concise account of barium, drawn up by Sir H. Davy, will probably be read with interest.

“To obtain *barium*,” says he, “a quantity of pure barytes is made into a paste with water, and placed on a plate of platinum; a cavity is made in the paste to receive a globule of mercury; the mercury is rendered negative, the platinum positive, by means of a voltaic battery, containing about 100 double plates.

“In a short time an amalgam will be formed, consisting of mercury and barium. This amalgam must be introduced into a little tube made of glass, free from lead, which must be bent in the form of a retort, filled with the vapour of naphtha, and hermetically sealed. Heat must be applied to the end of the tube

containing the amalgam, till all the mercury has been driven off; there will remain a solid difficultly-fusible metal, which is barium.

“ I first gained indications of the decomposition of barytes in the end of October 1807, and I obtained an alloy of it with iron in March 1808. The process of electrifying mercury in contact with the earth, was pointed out to me in the course of my inquiries by MM. Berzelius and Pontin of Stockholm, in May 1808; and in the beginning of June in the same year I obtained *the metal*.

“ Barium, as procured by heating the amalgam, appeared of a dark gray colour, with a lustre inferior to that of cast-iron. It was considerably heavier than sulphuric acid; for though surrounded by globules of gas, it sunk immediately in that fluid. It instantly became covered with a crust of barytes when exposed to the air, and burnt with a deep red light when gently heated. When thrown into water it effervesced violently, disappeared, and the water was found to be a solution of barytes.

“ Barium as yet has been obtained only in very minute quantities. I have never possessed enough of it to ascertain its general chemical and physical characters, and no experiments upon it have been published by any other person.”—*Elem. Chem. Phil.*, page 338.

Dr. Clarke of Cambridge, by exposing dry nitrate of barytes on charcoal to the intense heat of the condensed hydroxygen flame, observed metallic globules in the midst of the boiling fluid, and the charcoal was found to be studded over with innumerable globules of a pure metal of the most brilliant lustre and whiteness. On letting these globules fall from the charcoal into water, hydrogen was evolved in a continued stream. *Ure's Dictionary*.

Thus have we seen that there are two minerals abundantly distributed in nature; the one called *witherite* or carbonate of barytes, the other *carwk* or sulphate of barytes; and that by various means the carbonic and sulphuric acids may be detached, and the earth, or pure barytes, obtained in a separate state. We have seen also, that the barytic earth itself is a compound body,—the oxide of a peculiar metal,—and that by means of voltaic electricity, the oxygen may be abstracted from it, and the metallic base separately obtained.

Nothing now remains but to offer a few remarks on the uses to which this singular earth may be applied.

Hitherto it has chiefly been employed as a chemical test, and in the formation of certain barytic salts already described. It has also been used by a few scientific physicians, in certain diseases, with very good effect.

In the year 1784 Dr. Crawford made his first experiments on the powers of muriate of barytes on the animal economy; and in the year 1788 many trials were made of it in desperate cases admitted into St. Thomas's Hospital¹, and in a variety of instances these attempts proved remarkably successful. An account of the cases in which it was more particularly useful may be seen in the work quoted below.

It has been often said, that there is a fashion in medicine; but it is a singular circumstance, that the English physicians, who were the first to employ barytes as a medicine, should nearly give up its use, when the French, who had been in the habit of giving muriate of lime for scrofulous diseases, began to use it; and that we in our turn should adopt the muriate of lime, which is now the common English medicine for such complaints, after the French had abandoned it.

Considering, however, the poisonous quality of barytes, it will surely be necessary to institute many experiments before sufficient confidence in its safety can be acquired, or before the nature of its effects on the animal economy can be thoroughly understood and properly appreciated².

In preparing the medicine, the utmost care should be taken to have it perfectly pure; for some specimens of the carbonate of barytes contain copper, and others arsenic. An attention should also be paid to the saturation of the acid; for it will be very difficult to obtain an uniformity in the doses, unless a saturated solution be always employed, or the water be fully saturated, whenever the medicine is prepared by dissolving the crystallized salt: not but that a solution, however dilute, might be employed, if the exact quantity of barytes in each dose could be accurately ascertained.

Dr. Crawford has, however, remarked, that if a saturated solution be administered, a *very small* quantity of muriatic acid should be previously added to each dose, to remove the bitter taste which is peculiar to this salt, and occasion it to sit pleasantly on the stomach. But no unskilful person should ever venture to administer barytes internally, in any form.

From the appearances which pure barytes presents when slaked, and especially from its ready solubility in water, one

¹ See a paper on the medicinal properties of the muriated barytes, by Dr. Adair Crawford, in vol. ii. of the *Medical Communications*, London, 1790, pages 301—360.

² I am credibly informed that the muriate of barytes has been found to be a specific in some obstinate cases of worms, which had resisted all the common formulæ; and that a nostrum, which has been very justly celebrated for the cure of this complaint, has barytes for its base.

would suppose it would be useful in making hard and tenacious cements, particularly for important purposes. This I think was hinted by one of the French chemists; but I never heard of its having been employed in this way.

It may, however, be tried at a trifling expense (by any one who is in possession of a good reverberatory furnace) upon the sulphate of barytes. This, when ground small and mixed with one-third of its weight of pulverized charcoal, should be submitted to a red heat, as before mentioned, in order to convert the acid to sulphur. To effect this, the barytic salt, mixed as above, must be put into strong iron vessels, and well covered by charcoal to prevent the access of atmospheric air, which would not fail to re-convert the sulphur to sulphuric acid; and then submitted to the continued heat of a furnace. The sulphuret of barytes which will result is to be decomposed by any of the common means, and the remaining earth preserved for use in close vessels.

For some underground works of importance, this earth might be highly valuable and useful. As a cement for porcelain and glass, I should think it would surpass every other preparation. Nevertheless, it must be remembered, that every thing would depend upon its being applied at the moment of its being mixt with the water.

But there is a purpose not yet mentioned, to which this peculiar substance might be applied, that would be of more importance, medicine excepted, than any other for which it can be used. I allude to the decomposition of the alkaline sulphates, and the separation of their alkali.

Whenever the carbonate of this earth shall be found in as great plenty as its sulphate, we shall have within ourselves ample means of preparing the mineral alkali, and not be dependent on Spain and other places, as is the case at present; or if the native carbonate could not be obtained, it might answer to employ the sulphate in the decomposition of common salt, though it would be necessary to convert the sulphate into a sulphuret, and then to separate the sulphur by some other process³.

If the barytic earth, thus prepared, be simply thrown into a solution of sulphate of soda, it will immediately occasion its decomposition, and sulphate of barytes with caustic soda will be produced.

³ The opinions of those respectable chemists, Messrs. Guyton and Carny, respecting the means which ought to be adopted in preparing the native barytic salts, for the decomposition of the alkaline residuums, may be seen in the *Annales de Chimie*, tom. xix. page 109—113.

ESSAY V.

ON CARBON.

CARBON is a name now universally adopted for charcoal, or rather for that pure part of its basis which, during combustion, combines with oxygen, and escapes in the form of carbonic acid or fixed air. Carbon is so abundant in nature, that it occurs plentifully in the animal, the vegetable, and the mineral kingdoms; in combination with gas, with fluids, and with solids. It is found in the bowels of the earth, in the mines of plumbago, anthracolite, jet, glance coal, and in every kind of pit coal, of which it forms the most material part. It is also separated from the lungs of all animals in the act of respiration; and it is the basis or skeleton of all vegetables, from the small anemone of the garden to the huge oak of the forest.

Notwithstanding this abundant distribution of carbon, there is some doubt whether it has ever occurred perfectly pure in nature. The most pure state in which it has ever yet been seen is certainly that of the *diamond*, which, though deemed to be the most valuable of the precious stones¹, and classed with them, is now found to be nothing more than crystallized carbon, so far as the most careful chemical analysis has yet been able to discover. The precious stones are chiefly composed of one or more of the earths and metals; the diamond, on the contrary, contains no portion of any substance belonging to either of those classes of bodies; though Sir H. Davy has asserted that it contains a small portion of oxygen.

There is, however, a great difficulty attending this subject. Has the diamond been dissolved in water in the bowels of the earth, or could it otherwise have acquired that peculiar crystalline form in which we see it?—And yet we cannot comprehend how it could be dissolved in that fluid; for, in our hands, water has no action whatever upon it, nor does water exert any solvent

¹ Diamonds are sold by the carat, a weight equivalent to four grains. Unblemished diamonds, when polished, are worth about 6*l*. per carat. The mode of calculating their value is by squaring the number of carats which the diamond weighs, and then multiplying the amount by the agreed price of a single carat. Thus it is, that those which are of an unusual size always cost immense sums. That at the court of Russia, which weighs 779 carats, would, upon this calculation, amount to upwards of three millions six hundred and forty thousand pounds sterling. But the value of brilliants is often modified by their form, as has been very satisfactorily shown by Mr. Jeffries in his very lucid and ingenious treatise. See Jeffries *On Diamonds and Pearls*, 69 octavo pages, with 30 plates, price one guinea.

Looke Oven

Fig. 1

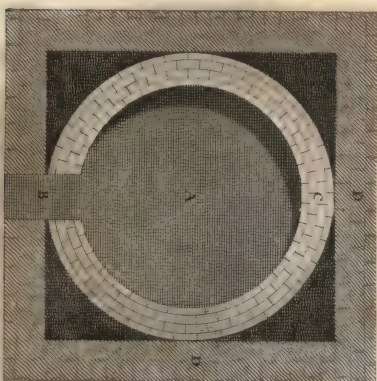


Fig. 1 Ground Plan.
A Open Floor...
B Door way...
C Door wall...
D Wall of stones



Fig. 3

Fig. 2 Elevation.
a Open Floor...
b Wall of wall...
c Door way...
d Roof of oven

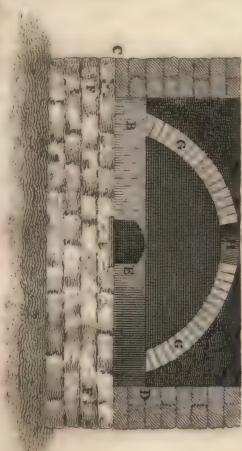


Fig. 2

Scale of Feet
1 2 3 4 5 6 7 8 9 10 11 12

J. Tinkler del.

W. Davis sculp.

Fig. 3. New Method of Drawing 'Looke into' Looke.



power on carbon, in any state in which we can submit it to its action.

The diamond is indeed the hardest substance in nature, and hence there is no way of grinding or polishing diamonds but by acting upon them with their own powder, which is obtained by laborious rubbing of them one against another. This method, together with the art of polishing diamonds, was brought into Europe in the year 1456. If the diamond be exposed to the sun, it refracts and decomposes the rays of light more effectually than any other transparent body.

Carbon has neither taste nor smell; it is a bad conductor of heat; is altogether insoluble in water, and is perfectly infusible by the strongest fire that can be applied, provided it be defended completely from the access of atmospheric or any other air containing oxygen. It has also the property of deoxidizing the oxides of metals, and other combustible substances; and of decomposing many of the sulphuric salts. In a crystallized state, it forms, as we have seen, the diamond. The representative number of carbon is 6.

Rouelle the younger proposed a problem in the *Journal de Médecine* for October 1762, which shows that he imagined he could dissolve vegetable coal in the palm of the hand². How he could effect this I confess I have no idea, as none of the fluid menstria with which we are acquainted have any perceptible action whatever, as solvents, upon carbon.

Strong nitrous acid, by peculiar management, may, we know, be made to inflame carbon, and when once thus inflamed it will burn with considerable brilliancy; but this arises from the decomposition of the acid, and is owing to the rapid combination of its oxygen with the charcoal, for which it has a powerful affinity.

Carbon, in certain states, combines readily with oxygen; and two distinct combinations may be formed by their union, viz. carbonic oxide and carbonic acid. Both these are gaseous products; and as the latter contains the lesser proportion of carbon, and was the first discovered, we shall speak of this in the first instance.

Carbonic acid is always produced by the burning of charcoal or other carbonaceous matter in oxygen gas or in atmospheric air. It is not necessary, however, to burn charcoal for the production of this gas, as it may be obtained more easily from powdered chalk, limestone, or marble, by the action of diluted

² Other curious experiments by Rouelle may be seen in *Mém. de l'Acad. Roy. de Paris*, Année 1747, page 49, &c.

sulphuric or muriatic acid, and by receiving the gas over water or mercury as it is evolved. It is also produced in every case of vinous fermentation, is given out during the decomposition of animal and vegetable substances, and is very abundantly thrown off by the action of fire in the process of lime-burning.

For the knowledge of carbonic acid we are indebted to the late Dr. Black, who discovered it in the year 1755: Mr. Keir first suspected it to have acid properties, but its composition was not known until 1772, when this was ascertained by Lavoisier, who in the same year burnt a diamond, and found the product to be carbonic acid gas. Certain individuals in the Academy del Cimento at Florence, nearly eighty years before this, had been able to burn the diamond by means of a lens, but they seem to have had no idea of the real nature of the product of the combustion. Those of my readers who shall be desirous of repeating this experiment, will be glad to be informed, that a drawing of a new and complete apparatus for this purpose may be seen in Mr. Brande's *Manual of Chemistry*, second edition, vol. i. page 425.

Carbonic acid gas has the following properties. It has no colour, and consequently is invisible. It is a heavy gas, its specific gravity being to that of hydrogen as 20.7 to 1. One hundred cubical inches, at a mean temperature and pressure, weigh 46.37 grains. It is incapable of supporting combustion; for if it be poured from a jar or other vessel into one in which a taper is burning, the flame will be immediately extinguished.

Carbonic acid is not respirable; but when combined with water, it imparts to it a pleasant acidulous taste and an agreeable smell. At a mean temperature, and under the usual pressure of the atmosphere, water is capable of taking up carbonic acid equal to its own volume, and under the pressure of two atmospheres it will take up twice its volume; but whatever may be the quantity that it has condensed, the whole of it is easily expelled by heat. Carbonic acid combines readily with the alkalies, with what are called the alkaline earths, and with several of the metallic oxides, and with them forms those salts called carbonates. It changes litmus-paper, and some other of the delicate vegetable blues, to a red; and in the proportion in which it usually occurs in the atmosphere is favourable to the growth of vegetables; though in a large proportion it is injurious.

Carbonic acid is accumulated in immense quantities in the chalk-beds and in the mountains of limestone and marble; it is also found in abundance in many natural waters, such as those of Pyrmont, Spa and Seltzer; and these are imitated in London and other parts of the kingdom by the makers of what are called single and double soda water, which are prepared by the arti-

ficial impregnation of water with carbonic acid gas. For the methods of ascertaining the qualities of such waters, whether natural or artificial, Kirwan's *Essay on the Analysis of Mineral Waters* may be consulted, as it is the best work we have on the subject.

Carbonic acid abounds also in some wells and caverns, where, in consequence of its great specific gravity, it often occupies the lower part of a pit, while the upper is tolerably free from it. When in these situations, it is known to miners by the name of the *choak-damp*. The presence of this gas may be ascertained by letting down a lighted candle into the suspected well, in which, if it be unsafe to enter, the candle would be immediately extinguished; or by lowering a glass of lime-water, which is rendered turbid by the choak-damp, as carbonic acid precipitates lime in the state of carbonate of lime.

If hydrogen be taken as *unity*, the equivalent number for carbon will be 6; and this, when united with two proportionals of oxygen = 16, will form carbonic acid, which will consequently be represented by 22. Or its composition may be stated thus:

Carbon 27.3 + oxygen 72.7 = 100 carbonic acid.

Mr. Tennant was the first person who decomposed carbonic acid, which he effected by burning phosphorus in a close vessel, in which was a portion of carbonate of soda. The phosphorus combined with the oxygen of the carbonic acid, and the carbon appeared in the state of a black powder.

Sir H. Davy effected its decomposition by a different means,—by its action upon potassium. “If,” says he, “this metal is strongly heated in a retort containing the gas, the potassium takes fire and burns with a red light. Charcoal in fine powder is deposited, the gas disappears, and oxygen is found added to the potassium.”—*Elem. Chem. Phil.*, page 302.

Carbonic oxide is the other combination of carbon and oxygen. This gaseous product may be obtained from a variety of substances containing carbonic acid, by mixing such substances in favourable circumstances with others that are capable of abstracting a portion of oxygen from the carbonic acid; as by igniting together dried chalk and the filings of iron or zinc, taking equal weights of each; or by passing carbonic acid gas over charcoal heated to whiteness, in a tube of earthenware or porcelain. The gas should be well washed with lime-water to abstract any carbonic acid that may be attached to it; it may then be preserved in jars confined by water, as water absorbs not more than $\frac{1}{30}$ of its volume of carbonic oxide. This gas was one of the latest of Dr. Priestley's discoveries; and he obtained it by the ignition of the black oxide of iron with charcoal, and by heating a similar

oxide with the carbonate of barytes. We are, however, indebted to Mr. William Cruickshank of Woolwich for the true explanation of its nature and properties, in an interesting paper published by the late Mr. Nicholson in his *Journal* for April 1801, and in another paper in the month of September in the same year¹. Messrs. Clement and Desormes were, I believe, the first persons who undertook to verify Mr. Cruickshank's experiments, the result of whose examination was published in the *Annales de Chimie*, vol. xxxix. pages 26—64. Mr. Cruickshank discovered that those metallic oxides which retain their oxygen most obstinately, yield the greatest quantity of carbonic oxide².

Carbonic oxide may be passed through a red-hot porcelain tube without undergoing any change; it is however combustible, and when mixed with atmospheric air, burns with a lambent blue flame. It produces less heat than other inflammable gases, but may be inflamed at a much lower temperature. None of the metals exert any action upon it, except potassium and sodium, which at a red heat burn in it by abstracting its oxygen, and carbon is deposited. When burnt in a dry glass receiver of oxygen gas, no moisture is deposited on the glass, which shows that it contains no hydrogen. Like most other gases, it is invisible; its specific gravity is somewhat less than that of atmospheric air; its smell is offensive; it has the property of uniting with chlorine, and with it forming a highly interesting compound, which we shall describe hereafter: it is, as has already been said, combustible; but it is a gas that will not of itself either support combustion or animal respiration. It may be taken into the lungs, but is fatal to animal life. "I once took," says Sir H. Davy, "three inspirations of it mixed with about a quarter of common air; the effect was a temporary loss of sensation, which was succeeded by giddiness, sickness, acute pains in different parts of the body, and extreme debility; some days elapsed before I entirely recovered." Mr. Witter of Dublin was struck down in an apoplectic condition by breathing this gas; but he was speedily restored by the inhalation of oxygen. He has given an interesting account of the transaction in the *Philos. Mag.* vol. xliii. p. 367.

Carbonic oxide has a specific gravity when compared with hydrogen as 13.2 to 1; one hundred cubical inches of it weighing 29.7 grains. It contains more carbon, and yet is lighter than carbonic acid; carbonic acid being found to contain exactly twice as much oxygen as carbonic oxide. If the representative number of carbon be considered 6, as already stated, the composition of carbonic oxide gas will be one proportional of carbon 6 + one of oxygen 8 = 14 carbonic oxide.

¹ Nicholson's 4to *Journal*, vol. v. pages 1 and 201.

² *Ibid.* page 3.

Chlorocarbonic acid is a compound of carbonic oxide and chlorine. These two gases do not combine by mere mixture, or even by passing electric sparks through them: but by exposing a mixture of equal volumes to the intense light of the sun, they combine rapidly, and a condensation equal to half the original bulk takes place. The ingenious discoverer of this compound gas, Dr. John Davy, in consequence of the mode by which it is produced, named it *phosgene gas*. This acid gas has a very peculiar and remarkably pungent odour; it is the heaviest of all the known gases, 100 cubical inches of it weighing 105 grains, which is nearly four times as much as an equal volume of atmospheric air. It is decomposed by water, and the resulting gases, as might be expected, are muriatic and carbonic acid gases. The weight of chlorocarbonic acid to hydrogen is as 46.7 to 1. It is capable of saturating more of an alkali, or an alkaline earth, than any other acid. Four times its volume of ammoniacal gas is condensed by it, and a white salt is produced with a considerable evolution of caloric. Chlorocarbonic acid is a compound of one proportional of carbonic oxide $14 +$ chlorine $36 = 50$.

Carbon unites with *hydrogen*, and forms two gaseous products totally distinct from each other, the one called carburetted hydrogen gas, similar to what the miners call the fire-damp; the other super-carburetted hydrogen, or olefiant gas.

Carburetted hydrogen gas is carbon dissolved in hydrogen. In hot weather this gas is abundantly formed at the bottom of pools of stagnant water, and may be collected by means of a common pneumatic apparatus at its surface. It is procured in the large way by the dry distillation of pit-coal, and is the gas which is now employed for lighting the public streets, manufactories, &c. One pound of coal yields about 24 gallons of this gas, and as this always contains a portion of sulphuretted hydrogen and carbonic acid gas, it is usual to pass it through a mixture of lime and water, that these gases may be absorbed, and the carburetted hydrogen rendered sufficiently pure to pass into the gasometers for use.

As Professor Brande has been engaged in a laborious series of experiments on this gas, I conceive that I cannot do better than avail myself of his experience for the information of my readers.

“The specific gravity of the gases obtained from stagnant ponds is liable to great variation, 100 cubical inches weighing from 12 to 20 grains. They burn with a paler flame, and require less oxygen than *olefiant gas* for perfect combustion.

“The average specific gravity of purified coal gas is 0.4500 :

100 cubical inches weigh from 14 to 15 grains, and it may be considered as a mixture of about 55 volumes of hydrogen and 45 of olefiant gas.

“The best kind of coal for distillation is that which contains most bitumen and least sulphur. The chaldron should yield about 12,000 cubical feet of purified gas, of which each Argand burner, equal to six wax candles, may be considered as consuming from four to five cubical feet per hour.

“The economy of gas illumination may be judged of by examining the value of the products of the distillation of a chaldron of coals, the average cost of which may be considered as 3*l*. It should afford

	£.	s.	d.
1½ chaldron of coke, at 25 <i>s</i> . per chaldron . . .	1	11	3
24 gallons of tar and ammoniacal liquor, at 3 <i>d</i> . . .	0	6	0
12,000 cubic feet of gas, at 15 <i>s</i> . per 1000 feet . . .	9	0	0
	£10	17	3

“These products are taken at their lowest value; but they afford ample grounds for showing the advantage of gas illumination, not merely for public purposes, but also in private establishments. It appears that where more than fifty lights are required, a coal gas apparatus will be found profitable.”

It is however generally allowed, that the gas which is procured from oil affords more light according to its volume than coal gas; and it has been estimated that from two to three cubic feet may be regarded as equivalent to five or six of coal gas in this respect.

“The commonest whale oil,” says Mr. Brande, “or even pilchard dregs, quite unfit for burning in the usual way, afford abundance of excellent gas, requiring no other purification than passing through a refrigerator, to free it of a quantity of empyreumatic vapour.

“A gallon of whale oil affords about 100 cubical feet of gas, and an Argand burner equal to seven candles consumes a cubical foot and a half per hour. The cost of a lamp fed *by oil or coal gas*, and giving the light of seven candles, will be three farthings per hour. The cost of an Argand lamp with spermaceti oil 3*d*. per hour, mould candles 3½*d*., wax candles 14*d*.

“By a series of experiments, conducted with caution, I found that, to produce the light of ten wax candles for one hour, there were required 2600 cubical inches of olefiant gas, 4875 of oil gas, or 13,120 of coal gas.

“Experiments thus conducted show that purified *coal gas* seldom contains more than 40 per cent. in volume of carburetted hydrogen, while *oil gas* generally affords about 75 per cent.;

hence its superiority for burning, and the relatively small quantity consumed ¹."

M. Berthollet instituted a series of experiments on the decomposition of oil for the production of gas, which may be considered important from the results which he obtained. The product which is usually afforded, is a *mixture* of gases; but this experimental philosopher, by a judicious regulation of the temperature, prevented the other gases from rising, and obtained olefiant gas in a state of purity ².

An ingenious and highly estimable friend of mine, who has lately been engaged in lighting some of the principal streets of Paris with oil gas, does it in a way never before attempted. He thus writes: "We are going on quite a new principle. Coal is very dear and bad here, and it struck me that the oleaginous seeds, which are cheap and abundant, might answer the purpose. We made our experiments, and found that by this means we can produce a cheaper and better gas than from coal, and more so than from oil. For by taking the oil seeds we save all the waste and expense of extracting the oil, and have the substance in a much fitter state for decomposition. We have a patent for this invention in France, and have met with great encouragement from the Government." How delightful is it to observe that the constituted authorities in every country of Europe are lending their assistance in the prosecution of schemes of improvement, and in aiding the efforts of individuals for increasing the comfort, and promoting the civilization of the general community!

I had hitherto forgotten to observe that Dr. Henry has devoted a considerable time to the investigation of the nature of the gas from mineral coal; and this is the more inexcusable, as he was the first experimental philosopher who avowed that he did not consider this to be a subject beneath his notice.

So early as the year 1805 Dr. Henry instituted a series of "experiments on the gases obtained from wood, peat, pit-coal, oil, wax, &c. with a view to the theory of their combustion, when employed as sources of artificial light," and the result of his experiments was published in Nicholson's *Journal*, 8vo, vol. xi. page 65—75. This memoir contains a table of results, and a variety of very interesting observations. Three years afterwards this ingenious philosopher resumed his experiments, an account of which may be seen in the *Phil. Trans.* 1808, page 282, &c.; and in the latter end of the year 1818 and the beginning of the following year, in consequence of an application from the pro-

¹ Brande's *Manual*, vol. i. pages 438—442. *Journal of Science*, vol. i. pages 71—80.

² *Mémoires de la Soc. d'Arcueil*, tom. ii. 84. and tom. iii. 154.

prietors of some large manufactories lighted by gas in the neighbourhood of Manchester, he once more returned to the investigation of the subject. The paper giving an account of these latter experiments was read to the Literary and Philosophical Society of Manchester on the 19th March 1819, and afterwards published in their Memoirs, vol. iii. page 391—429. It consists of distinct chapters on the following subjects, viz. on the gases of known composition, the mixtures of which, in various proportions, according to his view, compose all the varieties; on the quality of the gas at different stages of the distillation; on the purification of coal gas; on the method of analysis; and on the chemical nature of the gas from coal; together with several tabular representations, all which deserve the attention of those persons who are desirous of becoming thoroughly acquainted with this subject.

Before the middle of the last century, the Rev. Dr. John Clayton ascertained by experiment, that mineral coal evolves a permanently elastic fluid, fit for the purposes of affording light and heat; and he communicated the discovery in a letter to the Hon. Robert Boyle. This letter was read before the Royal Society in January 1739, and in the year 1741 was printed in the Society's *Transactions*, vol. xli. page 59. The discoverer calls the gas the *spirit of coals*. The circumstances which he relates as having led to the discovery, are highly interesting; but on reading the Doctor's account of the results which he obtained, it seems very extraordinary that neither he nor any of the fellows of the Royal Society, nor others to whom the experiment was shown, should have thought of turning it to an economical account.

For the first application of carburetted hydrogen gas to the purpose of illumination, the public is certainly indebted to Mr. W. Murdoch, the particulars of which Dr. Henry first published in the year 1805 as a postscript to an account of his own experiments¹. From this communication I can only make a few brief extracts, and must refer to the paper itself for the remainder.

In the year 1792, at which time Mr. Murdoch resided at Redruth in Cornwall, as principal agent for Messrs. Boulton and Watt in that county, he commenced a series of experiments upon the quantity and quality of the gases contained in different substances. In the course of these, he remarked that the gas obtained from coal burnt with great brilliancy upon being set fire to; and it occurred to him, that by confining and conducting it through tubes, it might be employed as an economical substitute for lamps and candles.

At this time Mr. Murdoch was too much engaged to attend

¹ Nicholson's *Journal*, vol. xi. page 73.

further to the subject; but in 1797 he repeated the experiments in presence of numerous spectators at Old Cumnock in Ayrshire, and in 1798 he actually constructed an apparatus at Soho foundery, which was applied during many successive nights to the lighting of the building. These experiments were occasionally continued until the spring of the year 1802, when upon the occasion of the public rejoicings for the peace, the illumination of the whole of the Soho manufactory afforded an opportunity of making a display of the new lights; and they were made to constitute a principal feature in that exhibition.

Three years after this public display at Birmingham Messrs. Phillips and Lee of Manchester lighted up their extensive establishment in that town with coal gas issuing from nearly a thousand burners. This grand application of the new principle satisfied the public mind, not only of the practicability, but also of the economy of the application; and as a mark of the high opinion they entertained of his genius and perseverance, and in order to put the question respecting the priority of the discovery beyond all doubt, the Council of the Royal Society awarded to Mr. Murdoch the gold and the silver medal founded by the late Count Rumford.

Nothing but the importance² of the application of the gases from oil and coal could have justified me in going so far into detail, especially if I had had to explain the nature of the carburetted gas which perpetually occurs in the coal districts, and which it would have been incumbent upon me to have treated of in this essay, if I had not anticipated the subject in the Essay on Temperature, pages 64—71. I proceed now to consider the nature of the other gaseous compounds of carbon.

Super-carburetted hydrogen is a compound of carbon and hydrogen, in which the hydrogen combines with exactly twice as much carbon as it does in the carburetted hydrogen gas already described. It is highly inflammable, and emits more light during its combustion than is given out by the inflammation of the former. This super-carburetted gas is now generally known by the name of *olefiant* gas; and under that name has been already referred to in the former parts of this essay.

Olefiant gas is generally evolved during the destructive distillation of oil, pit-coal, and other substances; but for the purpose of experiment it is usually procured by heating a mixture of four parts of sulphuric acid and one of alcohol in a retort, and col-

² The manufacture of coal gas is important in another view, as the waste liquor now furnishes most of the subcarbonate of ammonia, the common smelling salts of the shops, and is also employed with great advantage as a manure for land.

lecting the gas over water as it is generated. When kindled, it burns with a beautiful white flame of great splendour. One volume of this gas, in consequence of the condensation of its hydrogen, requires three volumes of oxygen for its combustion, during which two volumes of carbonic acid are produced. Heat alone will decompose it; for if one volume of this gas be frequently passed through a ret-hot tube, the hydrogen will deposit its charcoal, and become expanded to two volumes, its natural bulk.

The decomposition of olefiant gas, by heating it in conjunction with oxygen, affords a beautiful exemplification of the system of definite proportions, thus: 1 proportional of carbon 6 + 1 prop. of hydrogen 1 = 7 olefiant gas. If this be mixed with 3 prop. of oxygen $8 \times 3 = 24$ making 31, the mixture on detonation will produce as under:

The 1 prop. of hydrogen 1 + 8.0 oxygen = 9.0 water.

The 1 prop. of carbon 6.0 + 16.0 oxygen = 22.0 carbonic acid.

31.0

Carburetted hydrogen is compounded of one proportional of carbon and two of hydrogen; whereas olefiant gas is a compound of one proportional of carbon and one of hydrogen; and may be represented thus:—One proportional of carbon 6.0 + one of hydrogen 1, will give the representative number of 7.0 for super-carburetted hydrogen or olefiant gas.

Chloric ether may be formed by allowing a current of chlorine and one of olefiant gas to meet in a proper receiver. There should be excess of olefiant gas; for if the chlorine be in excess, the liquid absorbs it. It is transparent and colourless; its taste sweet and somewhat acrid; its specific gravity 1.2. It boils at 152° . It burns with a green flame, evolving muriatic acid, and largely depositing charcoal. As it is produced by equal volumes of chlorine and olefiant gas, it is probably a compound of one proportional of chlorine 36.0 + two of olefiant gas $7.0 \times 2 = 14.0 = 50$ chloric ether¹.

Perchloride of carbon. Mr. Faraday has ascertained that, by exposing olefiant gas, mixed with great excess of chlorine, to the action of light, a white crystalline substance is formed, which, when purified by washing with water, is a perchloride of carbon. This substance is nearly tasteless; its odour resembles camphor; its specific gravity is about 2; it is a non-conductor of electricity. It is volatile; and in close vessels fuses at 320° , and boils at 360° . It is not very combustible, but burns when held in the flame of a spirit lamp, with the emission of much smoke and acid fumes.

¹ Brande, vol. i. page 437.

It is insoluble in water, but readily soluble in alcohol and ether, and the solutions deposit arborescent and quadrangular crystals. It also dissolves both in volatile and in fixed oils. It is scarcely acted upon by alkaline and acid solutions; but most of the metals decompose this substance at a red heat. Potassium burns brilliantly in its vapour, causing the deposition of carbon, and the production of chloride of potassium. It appears from various analytical experiments upon this compound, that 100 parts afford 10 carbon and 90 chlorine; whence it would appear to consist of 2 proportionals of carbon $12 + 3$ of chlorine 108, making its equivalent number 120.

Protochloride of carbon. When the perchloride of carbon is passed through a red-hot tube, containing fragments of rock crystal to increase the heated surface, it gives off a portion of chlorine, and is converted into a liquid protochloride of carbon. It is a limpid colourless fluid; specific gravity 1.55, and not combustible, except retained in the flame of the spirit lamp, when it burns with a yellow flame, much smoke, and fumes of muriatic acid. It does not congeal at 0° ; it rises in vapour at about 165° . It is insoluble in water, but soluble in alcohol, ether, and the oils. It is not affected by the acids or alkalies, nor, at common temperatures, by solutions of silver. It dissolves chlorine, iodine, sulphur and phosphorus². This extraordinary substance affords, when decomposed, 14 parts carbon and 84 chlorine; whence it may be inferred to consist of 1 prop. of carbon $6 + 1$ of chlorine $36 = 42$.

Hydriodide of carbon. When iodine and carburetted hydrogen are exposed to the action of light, they combine and form a hydriodide of carbon. This compound was first obtained, in the laboratory of the Royal Institution, by Mr. Faraday. The hydriodide of carbon is a white crystalline solid, volatile without decomposition, and in many respects analogous to the hydrochloride of carbon, or chloric ether above described. Its taste is sweet, and its odour aromatic³.

Carburet of nitrogen. This gas was discovered by Gay Lussac, and announced in the *Annales de Chimie* for 1815, vol. xcv. page 136—231, under the name of *cyanogen*. It is here generally called prussic gas. It may be obtained by decomposing the cyanuret, or prussiate of mercury, by heat. It has a very powerful smell, somewhat like that of bitter almonds, and affects the nostrils violently when inhaled by them. It is a permanently elastic fluid, very inflammable, and nearly twice as heavy as atmospheric air; its specific gravity, compared with hydrogen, being 24.4.

² Brande, vol. i. pages 433 & 434.

³ *Id. ibid.* 438.

One hundred cubic inches of it weigh 54.9 grains. Water dissolves 4.5 volumes, and alcohol 23 volumes of this gas. The aqueous solution is sharp and penetrating to the taste, and highly poisonous. The gas burns with a beautiful purple flame inclining more to blue than red. Carburet of nitrogen, or prussic gas, consists of two proportionals of carbon $12.0 +$ one of nitrogen $14.0 = 26.0$, which may be considered to be the representative number of this gaseous compound.

Chlorocyanic acid. This compound of the prussic and chlorine gases was first formed by M. Gay Lussac, and described by him in the paper already alluded to in the 95th volume of the *Annales de Chimie*. He obtained it by passing a stream of chlorine gas into a solution of hydrocyanic or prussic acid in water; and purified it from the excess of chlorine in a way he there describes. It is void of colour and very volatile. It has a pungent and very peculiar odour; and reddens litmus like other acids. M. Gay Lussac gave it the name of chlorocyanic acid. It is composed of one prop. of cyanogen $26.0 +$ one of chlorine $36.0 = 62$ chlorocyanic acid.

Hydrocyanic or prussic acid. This is a triple compound of carbon, nitrogen and hydrogen; or hydrogen united with prussic gas. It is usually obtained by distilling at a very low heat moistened prussiate of mercury with muriatic acid. The acid thus obtained is a colourless liquid, has a strong smell resembling peach blossoms, its taste is very acid and highly poisonous. At first it gives an impression of sweetness and coolness to the tongue, it then tastes hot and virulent, and sometimes excites sickness and fainting, and often violent coughing. It is a volatile acid, and when exposed the gas volatilizes so rapidly as to freeze itself. This may be shown by taking a drop of it on the end of a tube. It reddens litmus paper, but the red disappears as the acid evaporates¹. This acid contains more nitrogen than the other animal acids, but is destitute of oxygen. It is sometimes employed in medicine, but it is preserved with difficulty, as it is the most easily decomposed of all the acids. Some observations by Sir H. Davy on the prussic gas and prussic acid, will be found in two distinct papers in the 1st volume of the *Scientific Journal*, pages 283 and 288. We have seen that cyanogen or prussic gas is a compound of carbon $12.0 +$ nitrogen 14.0 ; the prussic acid is a similar compound, with the addition of one proportional of hydrogen 1, which makes the representative number 26.0.

Cyanogen and Iodine. This compound has been formed by Sir H. Davy, by heating iodine with prussiate of mercury.

¹ Mr. Porret *Philos. Trans.* for 1814. M. Gay Lussac *Annales de Chimie*, tome xcv. pages 136 &c.

“The compound,” says he, “is a very curious body; it is volatile at a moderate heat, and on cooling collects in flocculi, adhering together like oxide of zinc formed by combustion, and it has a very acrid taste and pungent smell.” In this paper he intimates a wish that M. Gay Lussac could be prevailed upon to give up the inexpressive and difficult names of *cyanogen* and *hydrocyanic acid*, and to adopt the simple ones of *prussic gas* and *prussic acid*².

Sulphuret of carbon. This is a colourless liquid of the specific gravity of 1.272, highly inflammable, and capable of forming compounds with the earths and alkalies. It boils at 106°, though it has so considerable a specific gravity, and does not freeze when cooled down to -60°. Its taste is pungent, and its odour very fetid. It was discovered by Lampadius, who from its extreme volatility gave it the name of *alcohol of sulphur*. It is obtained by passing the fumes of sulphur over red-hot charcoal. Dr. Marcet has discovered that sulphuret of carbon has the property of producing cold far exceeding that of any other known substance. In the receiver of an air pump mercury may be readily frozen by its means. Iodine dissolves in sulphuret of carbon, and changes it to a dark reddish brown colour. One grain of iodine will impart a deep colour to 1000 grains of the liquid. Sulphuret of carbon is a compound of one proportional of carbon 6 + two of sulphur 32 = 38. Messrs. Clement and Desormes, in a paper on carbon; M. Berzelius; and Professor Brande, have written on this curious compound fluid³.

Phosphuret of carbon. The formation of this substance was first noticed by Proust, who described it under the above name in the *Annales de Chimie*. There is some difficulty in obtaining it as he directs; but Dr. Thomson says he never failed to procure it by the following method: “Allow phosphuret of lime to remain in water till it has given out all its phosphuretted hydrogen gas; then add to the liquid a considerable excess of muriatic acid; agitate for a few moments, and throw the whole upon a filter. Phosphuret of carbon will be found upon the filter, which is to be washed and dried.

“Phosphuret of carbon thus obtained, is a soft powder of a dirty lemon yellow colour, without either taste or smell. When left in the open air, it very slowly imbibes moisture, emits the smell of carburetted hydrogen, and acquires an acid taste. When the powder is thrown over the fire in small quantities at a

² *Journal of Science and the Arts*, vol. i. 289.

³ Lampadius in Crell's *Annals*, 1796, ii. Clement, *Annales de Chimie*, tome xlii. p. 121—152. Berzelius and Marcet, *Philosophical Transactions*, 1813. Brande, *Phil. Trans.* 1820, page 19.

time, it burns in beautiful flashes." It is composed of one proportional of phosphorus 12 + one of carbon 6.

In treating of carbon it is usual to adduce charcoal as a familiar instance of its existence, carbon being the basis of all charcoal. On this account it may be proper to speak of the methods used for obtaining this article, and also of its peculiar properties.

Charcoal is too well known to require any minute description; but as every one may not be aware of its characteristic properties, it will be necessary to speak more circumstantially respecting them than I have hitherto under the word Carbon.

The charcoal of wood is light and porous, so much so that it is possible to blow entirely through it. It is also very brittle, and easily reduced to a fine powder; it absorbs light very abundantly, which occasions its blackness; at a red heat it decomposes water and reduces metallic oxides; it absorbs all the gases in abundance; it decomposes many of the acids by abstracting their oxygen; it is a powerful antiseptic; is unalterable and indestructible by age; is a conductor of electricity and a bad conductor of heat; it has a great affinity for oxygen when ignited; it is a useful agent in purifying rancid oils, and in abstracting the colour from syrups and saline solutions; it is one of the principal articles employed in the preparation of Mr. Hatchett's artificial tannin; and it is one of the bases of the prussic acid and of a great many other compounds.

One of the most important of these combinations is the article of gunpowder, which is generally made to contain about fifteen per cent. of charcoal. The usual proportions of its ingredients are 76 parts of well purified nitre, 9 of sulphur, and 15 of charcoal.

The first intimation that was given of gunpowder, was by that great philosopher Roger Bacon, in his posthumous treatise entitled, *De Nullitate Magiæ*, published at Oxford in 1316, nearly 150 years before the invention of printing, and about 22 years after the death of its venerable author. "You may," says he, "raise thunder and lightning at pleasure, by only taking sulphur, nitre, and charcoal, which singly have no effect, but mixed together, and confined in a close place, cause a noise and explosion greater than that of a clap of thunder."

It is observable that he only mentions the sulphur and nitre in direct terms; and, as though he were fearful of imparting the dread secret, conceals the charcoal under an anagram. The words are, "*sed tamen salis petrae lure mope can ubre, et sulphuris, et sic facies tonitrum, et corruscationem, si scias, artificium.*" The words which are printed in italics form an anagram of CARBONUM PULVERE, charcoal powder.

Polydore Vergil relates, that gunpowder was invented by

Bartholdus Schwartz, a German chemist, who happening to triturate some sulphur, nitre, and charcoal in a mortar, was surprised and alarmed at an unexpected explosion, which blew off the head of his mortar to a considerable distance.

The probability is, that this was a *second* discovery of the same thing, and that he knew nothing of the disclosure which Bacon had made, and who was doubtless in possession of the secret 100 years before the time alluded to by this author.

It appears, however, that in the year 1380 Bartholdus Schwartz did actually instruct the Venetians in the use of gunpowder, and that all Italy complained of it, as a manifest innovation on the rules of warfare; although it is evident that this was not the first instance of the use of gunpowder in war; for it is related by Peter Mexia, that "when the Moors, in 1343, were besieged by Alphonsus XI. king of Castile, he discharged a sort of iron mortars upon them, which made a noise like thunder."

Similar effects, and even in a much higher degree, may be produced by the mixture of carbon with chlorate of potash and sulphur; and for some purposes this terrible compound is preferable to common gunpowder. Its explosive effects are truly astonishing. Some particulars respecting this new kind of gunpowder may be seen in the Additional Notes, No. LVI. of the Chemical Catechism.

"Pent in dark chambers of cylindric brass
Slumbers in grim repose the sooty mass;
Lit by the brilliant spark, from grain to grain
Runs the quick fire along the kindling train;
On the pain'd ear-drum bursts the sudden crash,
Starts the red flame, and death pursues the flash.
Fear's feeble hand directs the fiery darts,
And strength and courage yield to chemic arts."

Charcoal, when made on a large scale, is generally prepared in the following manner:—A large quantity of billet-wood is piled in a heap; this is covered with turfs and sand to prevent the access of atmospheric air as much as possible, and then the heap is set fire to at several holes near the bottom, which are always made for that purpose. At first a hole is left open at the top to occasion a draught, and produce a better and more regular combustion. After a time this orifice is covered with turf; and when it is perceived that the flame has pervaded every part of the heap, the holes at the bottom are closely stopped also. By this management the whole of the wood becomes ignited, though it is not burnt to ashes as it would be were a free circulation of air to be permitted; but, by closing the openings and leaving the fire smothered up, a heat is preserved sufficient to decompose and dissipate every thing of a fluid or gaseous nature in the wood, so as to leave the whole pile in a carbonized state.

The mass is then allowed to cool sufficiently to be uncovered, and the billets, now converted into charcoal, to be removed.

This method of making charcoal is doubtless very ancient. Theophrastus Eresius, the pupil and successor of Aristotle, who lived more than 300 years before Christ, has described it very fully. This excellent philosopher, who wrote more than 200 different treatises, chiefly on subjects of natural history, lamented, at the age of eighty-five, "that he was to die, just when he began to know how to live."

Pliny informs us that in his days the wood was formed into a pyramid, the apex of which was covered with clay¹. There is, indeed, abundance of evidence that the ancients were acquainted with several of the properties of charcoal, and employed it for various purposes.

It has, however, been discovered within a few years, that charcoal can be much more perfectly prepared by a method different from that which has just been described, and which is now generally adopted for the preparation of that which is consumed in the manufacture of gunpowder.

In this process the wood, previously freed from the bark, is placed within large cast-iron cylinders, which are fixed horizontally in brick-work so as to be easily heated red-hot by fires placed beneath them.

These cylinders during the distillation have no communication with the external air, but at one opening, and this is destined to allow of the escape of the acid and the different gases; so that, when the operation is over, nothing remains in the cylinders but the charred wood divested of all impurities.

In some manufactories the charcoal is drawn from the cylinders, while red-hot, into immensely large canisters, made with riveted plates of sheet-iron, and with moveable covers, which fit perfectly, so as to close them completely. In these it remains safely preserved from the action of the atmosphere till it is entirely cold. These canisters are so contrived, as to their number and size, as to contain the whole produce of one charge. I should be culpable, however, were I not to caution my readers against adopting this mode of conducting the business; for the circumstance of removing the charcoal from the cylinders while red-hot must very much injure the health of the workmen so employed.

In some other manufactories the wood is not put into the cylinders which are fixed in the brick-work, but into others which are made of sheet-iron, and contrived so as to fit within the former. Here the cast-iron cylinders acquire a red heat, as in

¹ Holland's *Pliny*, folio, London, 1601, book xvi. page 459.

the former case, and that heat is found to be sufficient to char the wood contained in the wrought-iron vessels.

When the operation is finished and the wood is found to be sufficiently charred, which is always known by the volatile parts having ceased to distil over, a block and tackle are affixed to the inner cylinders, which are drawn out in a moment, and others of the same dimensions, previously filled with billets of wood, are by the same means directly swung into their places. In this way the process goes on without interruption, and the proprietor is enabled to allow the charcoal to cool completely, before it is removed from the vessel in which it is prepared. In order to adhere strictly to this rule, it is of course requisite to have a number of the wrought-iron moveable cylinders proportionate to the extent of the work; so that while some are cooling, others may be recharged with wood, and exposed in the fixed cast-iron apparatus to the action of the fire, and thus no time will be fruitlessly expended. Drawings of the apparatus will be found in the plates, figures 13 and 14.

It is remarkable that, although the charcoal prepared by this process is so superior for making gunpowder, it is not well calculated for some other processes. It is not of half the specific gravity of the charcoal which is made out of doors in the common way, and merely covered up with turf. The makers of iron particularly will not buy it.

This method of working does however produce better charcoal for gunpowder, and it has the advantage of furnishing a large supply of an impure kind of vinegar, or acetic acid, which is very useful in several of our manufactories. This acid was formerly considered to be of a peculiar nature, and distinct from all others; it was named the *pyroligneous* acid, and in commerce it is still known by that appellation. Before this acid begins to distil over, there comes a peculiar fluid called naphtha or pyroligneous ether, which is used, when purified by a subsequent distillation with lime and animal charcoal, for spirit lamps, for the solution of shellac and the gums, and indeed for most purposes in which alcohol was formerly required; but at present the greatest consumption is by Mr. Macintosh in dissolving caoutchouc (Indian Rubber) for the preparation of his water-proof and air-proof cloth, for great coats, cloaks, &c.; and indeed to such perfection has he now brought it, that he makes air-tight pillow-cases and beds, which only require to be blown full of air by the mouth, to be ready for use when required, and in the morning the air may be let out and the bed folded up and put away into the traveller's trunk.

When this acid is suffered to stand a few weeks undisturbed, it deposits a peculiar kind of tar, and this in considerable quan-

tity. Every kind of wood will produce this acid and tar, when treated by what is called the destructive distillation. Peat also will yield it in abundance. A friend of mine distilled some which was dug in Wholmer Forest, and procured pyroligneous acid from it. When this acid was redistilled, it left a residuum of tar, similar to that which is produced from the second distillation of wood acid. For some years past this tar has been a great burden on the hands of those who have been largely concerned in making the pyroligneous acid. For, though it has been employed in a great variety of ways, the consumption has never kept pace with the quantity produced, and within my own knowledge many tons of it have been buried in the earth, merely to get rid of it.

It was tried in one of the public dock-yards; but the quantity produced at that time in Great Britain was, in comparison with the quantity of pitch and tar required for the royal navy, too insignificant to permit the idea to be ever entertained of its being generally used in the Government dock-yards; particularly as it will not combine with the imported pitch and tar in common use.

I have myself, in various ways, made experiments upon this tar; and, notwithstanding this inconvenience, I am so convinced of its value, that I am desirous of making it an object of public attention.

For every kind of wood fence, it is the best preservative of any thing that can be applied. It should be gently heated in an iron pot, and put on with a brush. When first put on, it gets so completely into the wood, that it might be supposed that it could be of little use. It soaks in, and seems to leave no *body*, as the artists express it: but if the work thus treated be examined after it has been exposed for some days to the sun, the surface and the texture of the wood will evidently be much altered; for it will now be found so impervious and hard, that it will be very difficult to make any impression upon it.

If a second, and especially if a third coat of this tar be put upon wood, it will then bear out, as the painters call it, sufficiently well; and I have reason to believe that it will preserve all outside wood-work much more effectually than it can be preserved by any other expedient that has hitherto been contrived for this very important purpose.

For ornamental paling, and indeed for all good outside work, a first, or perhaps a first and second, coat of this tar might be used with great advantage; and when these shall be completely dry, the work might be finished with white lead and oil, as usual.

Besides the extreme hardness which this article imparts to wood, it has also the advantage of effectually preserving it from worms and from all other insects. Even where wood has become

worm-eaten, I have observed that this tar will stop the progress of the decay; and I am inclined to think, from what I have seen, that a paling of worm-eaten deal, if it be not absolutely rotten, will last longer when covered with this article, than a similar fence made with new deal without such treatment. It may however be necessary to remark, that the article here spoken of is very different from the tar which is distilled from mineral coal, and that was recommended by the Earl of Dundonald, thirty years ago, for a similar purpose.

To those persons to whom a little additional expense would be no object of consideration, the following preparations are recommended. They will be found to improve the appearance of the wood to which it is applied very considerably: 1 gallon of the tar, 1oz. of tallow, and 2oz. of pulverized rosin, melted together and put on warm; or 1 gallon of the tar, and 2oz. of pulverized sulphate of iron, to be used in the same manner as the foregoing mixture.

The first of these prescriptions looks the best, but the latter has been proved, and has lasted good for twenty years. How much longer it will be an effectual preservative for the wood, time only can discover.

I have occasionally made many other trials of the tar from pyroligneous acid, and I find it useful not only for wood, but also as a varnish for a variety of goods made of rolled iron, or of cast iron. A more beautiful varnish for these purposes may however be prepared by the following process: Take 1 gallon of the wood tar, and $\frac{1}{2}$ pint of rectified spirits of wine, and let these be intimately mixed by a gentle heat.

If this composition be laid on hot and properly hardened by the air, it will prove a beautiful and durable black varnish.

Some time ago a very remarkable circumstance respecting the collection of pyroligneous acid from the charcoal-cylinders, came to my knowledge, which I think worth recording, as it may preserve some individuals from great loss and disappointment, and must be of considerable importance to us as a nation.

A gentleman of opulence, residing near the metropolis, who was the proprietor of some large gunpowder works, and who prepared his own charcoal for that manufactory, sustained a considerable pecuniary loss from the following occurrence.

He had for some time been collecting a portion of the pyroligneous acid, which arises from the wood in the act of charring; when a certain chemical adventurer persuaded him to make an alteration in the apparatus, with the view of procuring, as it was pretended, more than double the quantity of acid.

According to this advice, he put up at a considerable expense

an entirely new apparatus, which was so constructed that the pipes which conveyed the acid, as it arose from the ignited wood, passed through a large body of water, which so completely cooled it, that the whole of it was condensed and collected in the recipient. In the last pipe, exactly at the place where it emerged from the water, there was a small hole, to prevent any part of the apparatus from bursting. Whenever the cylinders had done working, it was directed that this hole should be firmly stopped, and that then the whole apparatus should be suffered to cool.

By this arrangement a much larger quantity of acid was preserved, as the adviser had predicted, and which promised an ample repayment of the expense of the alteration: but it was quickly perceived that the gunpowder was very much deteriorated; and this happening at a time when the house had a contract with Government (in which case the gunpowder is always accurately proved) several parcels were complained of, and one large delivery was actually returned as unfit for the public service.

These complaints were not only unexpected, but peculiarly mortifying, because the manufacturer had been pleasing himself with the idea that the gunpowder would be improved, and he could not at all account for the cause of this unfortunate change in the quality of his article.

At first he suspected that the nitre might contain some deliquescent salts; but even when he had made his gunpowder from the nitre which had been refined at His Majesty's private works, where the utmost care is taken in the process, the powder was still the same. Then the sulphur was examined; and when nothing amiss could be discovered there, he began, for the first time, to suspect that the fault must be in the charcoal, although that which they were then using was in appearance finer and handsomer than any they had ever had.

The proprietor was now, however, convinced that the alteration in the quality of the powder could not possibly be otherwise accounted for than by attributing it to this alteration in his apparatus: he therefore instantly ordered the whole to be removed, and reverted to his old plan of distillation, by which one-third, at least, of the acid is dissipated in gas, and entirely lost. But the consequence was evidently favourable, and the error fully detected. The gunpowder manufactured since is as good as it had formerly been, and he has received no more complaints.

This circumstance was not mentioned to me until after the new apparatus was destroyed, or I certainly would have advised the proprietor to continue the new arrangement, and to make no other alteration than merely to provide the means for the incondensable gaseous products to be properly dissipated. For, by

stopping up the vent-hole, the latter portions of the incondensable gas could not get away; and every chemist knows the property which charcoal has of absorbing with avidity all the gases, and in considerable quantity. If, instead of stopping up the vent-hole, several others had been opened during the last stage of the process, and suffered to remain so while the cylinders were cooling, I doubt not that this charcoal would have turned out equal in goodness to the former.

The kinds of wood which are preferred for making this kind of charcoal, are the dog-wood, the alder, and the willow¹; and since these woods have been made use of, and the last-mentioned process has been employed for making the charcoal, any given quantity of the British gunpowder will drive a ball one-third further than the powder prepared with ordinary charcoal.

This may in some measure be owing to the charcoal of these woods taking fire more quickly; for we know how much sooner the coal of some linen, when used as tinder, will take fire, than that of others, and how readily that kind of fungus burns which is called German tinder², a species of agaricus, known to botanists by the name of *Boletus igniarius*. The slightest spark communicated to this tinder will be sufficient to occasion a commencement of combustion.

The Government of France has for some time been aware of the importance of attending to the preparation of charcoal for public use. The old method was discontinued several years ago, and the gunpowder charcoal has since been made in large trenches cut within the ground, and lined with brick, the superintendents of the gunpowder works having found that by this management the same kinds of woods will produce lighter and softer charcoal than when the wood is carbonized in large piles in the open air³.

For philosophical experiments charcoal may be readily made by filling a large crucible with short pieces of wood, covering these with sand, and submitting the whole to a *red heat* for half an hour or more in a common fire-place. When I have had occasion to melt a block of tin, preparatory to making the nitrate or muriate of that metal, I have sometimes prepared very

¹ Within these twenty years very large plantations of dog-wood and alder have been made in the counties of Kent, Sussex, and Surry; so that at this time His Majesty's and other private manufactories of gunpowder are entirely supplied with charcoal from wood of the above descriptions.

² To render this fungus still more combustible, the Germans purify it from all extraneous matter by boiling it in an alkaline lye. They then dry it, and boil it again in a solution of saltpetre. Therefore the tinder sold in the shops is not the simple female agaric, but a compound of that vegetable production and nitre.

³ See Chaptal's *Chemistry applied to the Arts*, vol. ii. p. 288.

excellent charcoal by immersing pieces of wood in the melted metal, and holding them beneath the surface until the whole was charred entirely through. When this method is adopted, the charcoal may be plunged either into a vessel of mercury or a bed of cold sand, the moment it is drawn from the melting-pot, according to the purposes for which it may be wanted; and it will be found that by either of these modes it will be sufficiently preserved from the action of the atmosphere.

Whenever pieces of wood or other vegetable matters are charred without being disturbed during the operation, the grain of the wood and the form of the filaments are always preserved distinct and entire. If we examine writing paper or linen which has been covered up and burnt without the free access of atmospheric air, the wire marks of the paper and the threads of the linen will still be seen with distinctness.

When Sir William Hamilton explored the ruins of Herculaneum, he found corn that was converted to charcoal by the eruption of Vesuvius in the year 79 of the Christian era, and which was so well preserved that the grains of wheat were easily distinguishable from those of rye. We read indeed of some who have been so dexterous as to char an arrow without altering the form even of the feather¹.

On the contrary, if wood be burnt in the open air, the greatest part of it will be dissipated in gas. Common oak, if charred in a proper manner, will lose only from two-thirds to four-fifths of its weight; whereas if the same kind of wood be burnt in an open fire-place, the residuum of the combustion will not be more than about one 200th or one 250th of the original weight of the wood employed.

This, however, will vary according to the age and the dryness of the wood, and also to the different ways in which it may be burnt; and this accounts for the different statements which have been given of these results. Dr. Watson says that he procured 22 grains of charcoal from 96 of dry oak. Van Helmont, that 62lb. of the charcoal of oak will produce 1lb. of white ashes; whereas Sage says that 100lb. of charcoal will not give more than 2oz. of ashes.

The following table of the quantity of charcoal yielded by different woods, has been published by Mr. Mushet, from his own experiments in the small way, carefully conducted. He says, the woods before being charred were thoroughly dried, and pieces of each kind were selected as nearly alike in every respect as possible. One hundred parts of each sort were taken, and they produced as follows:

¹ Neumann's *Chemistry*, by Lewis, vol. ii. page 277.

Lignum Vitæ afforded	26.0	of charcoal of a grayish colour resembling coke.
Mahogany	25.4	tinged with brown, spongy and porous.
Laburnum	24.5	velvet black, compact, very hard.
Chesnut	23.2	glossy black, compact, firm.
Oak	22.6	black, close, very firm.
Walnut	20.6	dull black, close, firm.
Holly	19.9	dull black, loose and bulky.
Beech	19.9	dull black, spongy, firm.
Sycamore	19.7	fine black, bulky, moderately firm.
Elm	19.5	fine black, moderately firm.
Norway Pine	19.2	shining black, bulky, very soft.
Sallow	18.4	velvet black, bulky, loose and soft.
Ash	17.9	shining black, spongy, firm.
Birch	17.4	velvet black, bulky, firm.
Scottish Pine	16.4	tinged with brown, moderately firm.

Messrs. Allen and Pepys from 100 parts of the following woods obtained the quantities of charcoal as under :

Beech	15.00	Lignum Vitæ	17.25	Fir	18.17
Mahogany	15.75	Oak	17.40	Box	20.25

It is observable that the quantities obtained by Messrs. Allen and Pepys are in general less than those given by Mr. Mushet, which may be owing to Mr. Mushet not having applied sufficient heat, or operated long enough to dissipate the aqueous matter or the gaseous products. Charcoal was formerly considered to be a kind of *oxide* of carbon; but Messrs. Allen and Pepys have shown that this is not the case; and that when it is well prepared it requires as much oxygen for its complete combustion as the diamond².

To those persons who buy charcoal by weight, it is important to purchase it as soon after it is made as possible, as it quickly absorbs a considerable portion of water from the atmosphere. Different woods, however, differ in this respect. Messrs. Allen and Pepys found that by a week's exposure to the air, the charcoal of

Lignum Vitæ gained	9.6 per cent.	Beech gained	16.3 per cent.
Fir	13.0 ditto	Oak	16.5 ditto.
Box	14.0 ditto	Mahogany	18.0 ditto.

I have already adverted to the porosity of charcoal, page 162, and to the avidity with which fresh made charcoal absorbs all the gases. The following is a tabular view of the volumes of the different gases which were absorbed in the course of 24 hours, by one volume of charcoal, in the experiments of M. Theodore de Saussure, which were conducted in a way likely to produce correct results. Each portion of charcoal was heated afresh to a red heat, and allowed to cool under mercury. When taken from the mercury, it was instantly plunged into the vessel of gas.

² *Philosophical Transactions* for 1807, part ii. page 267.

Ammoniacal gas . . . 90	Nitrous oxide . . . 40	Oxygen gas . . . 9.25
Muriatic acid gas . . 85	Carbonic acid gas . . 35	Nitrogen 7.50
Sulphurous acid . . . 65	Bicarburett. hydr. 35.00	Carburetted hydr. 5.00
Sulphuretted hydrog. 55	Carbonic oxide . . 9.42	Hydrogen gas . . 1.75

I have already remarked, in another work, that a very interesting application may be made of this property of charcoal. The gases which are absorbed suffering so great a condensation, two gases introduced at once into the pores of the charcoal may perhaps be made to combine. Water has actually been formed from hydrogen and oxygen gases by this means ¹.

Caspar Neumann, who made many experiments on charcoal, informs us that for the reduction of the metallic oxides, the charcoal of the heavier woods, as that of the oak and the beech, is preferable, and that, for common fuel, such charcoal gives the greatest heat, and requires the most plentiful supply of air to keep it burning; while those of the lighter woods preserve a glowing heat with a much less draught of air; and that for purposes where it is desirable to have a steady and a still fire, charcoal should be employed which has been made from wood previously divested of its bark, since it is the cortical part which crackles and flies off in sparks during combustion, while the coal of the wood itself seldom does ².

For making crayons of charcoal, the willow is the best wood that can be employed, as the softness is in all its parts uniform. The coals of the hard woods, such as box and guaiacum, are considerably harder than others, while the charcoal of the kernels of fruits is peculiarly soft and friable ³. But as a pigment the coal of ivory is the most intensely black and the most beautiful. I speak here, not of the common ivory-black of the shops, but of the charcoal which is prepared by burning real ivory in closed vessels. As a powder for cleaning the teeth, the best charcoal is that made from the shell of the cocoa-nut.

The perfect durability of carbon as a pigment, may be seen in several of our old churchyards, where the letters made with lamp-black are still perfect, though the white lead with which the body of the stones was painted is entirely destroyed. Some few years ago I remember to have noticed this circumstance on Sir Hans Sloane's monument in the churchyard at Chelsea. This property of carbon is shown, however, in a more striking manner by the writings that were found in the ruins of Herculaneum, which have retained their original blackness for two thousand years. The ancients wrote with ink made from ground charcoal.

¹ *Chemical Catechism*, Addit. Notes, No. II. *Annales de Chimie*, vol. xxxii.

² Neumann's *Chemistry*, vol. ii. page 277.

³ See Lewis's *Commercium Technicum*, page 337; also Dr. Grew *On the Anatomy of Plants*.

A friend of mine, who is engaged in refining rancid fish oil by means of tannin, has fitted up an apparatus for burning the gelatinous or leather kind of precipitate which results from his operation, and which he says is of little value for any other purpose. This charred powder, or soot, he informs me, proves to be a finer and better black for printers' ink and other purposes, than any he can procure by other methods. I think it would be worth while to try this gelatinous precipitate, when properly charred, in abstracting the colour from sugar, refiners' syrups, and certain valuable saline solutions, as it is well known that *animal* charcoal is much more efficacious for such purposes than any kind of *vegetable* charcoal.

The article known in commerce by the name of lamp-black, is carbon in the state of a light impalpable powder, and is procured by burning the refuse of resin and pitch in peculiar furnaces, with long flues terminating in a close chamber, the ceiling of which is covered with porous cloth, through which the gas that is disengaged in the process may escape and the soot be left behind.

In drawing spirits of turpentine from the crude turpentine, there is a large residuum known in commerce by the name of *rosin*; and as a considerable portion is often found to be too impure to sell as rosin, it is profitably burnt for the production of lamp-black; and lately carburetted hydrogen has been obtained from it, much purer and giving a clearer and more vivid light than what is procured either from coal or oil. The library of the Royal Institution is lighted by means of gas produced from rosin.

The coal of all resinous substances is of a similar nature. If lamp-black be heated red-hot in a crucible, and allowed to cool before the crucible be uncovered, we shall have, perhaps, as perfect a sample of pure carbon as can easily be prepared. Sir H. Davy says, "The purest known form in which carbon can be obtained, is by passing oils or spirits of wine through ignited tubes. It then appears as an impalpable black powder: it has neither taste nor smell; it is a conductor of electricity, and it is more than twice as heavy as water."—*El. Chem. Phil.* page 299.

Some artists, for very nice purposes, have collected the carbonaceous matter which arises in burning the vegetable oils, by suspending some convenient substance at a proper distance over the flame of the lamp.

The beautiful brown pigment called *bistre* is prepared from an aqueous infusion of wood-soot. Some account of its preparation is related by Lewis in his "Commerce of the Arts," but more ample directions for making it are given in the French Encyclopedia.

If it be required to purify any carbonaceous matter, to render

it fitter for a pigment or other nice purpose, it may be done by first well calcining it in a close vessel, and then lixiviating it in water slightly acidulated by nitric acid. This process will separate the earthy or metallic particles with which it may be contaminated; and by heating it a second time in a very brisk fire properly secured from the air, we obtain a charcoal very near to the state of pure carbon.

Charcoal may also be obtained from animal substances burnt in closed vessels; but this differs from vegetable coal in some particulars, and, as I have already said, is better for some purposes. It is always more dense; and if it be made in a glass or earthen vessel, it adheres to it more than the carbon of vegetables; it is also less combustible, and generally contains phosphate of iron and other foreign matter.

It may be ascertained whether any carbonaceous matter be produced from animal or from vegetable substances, by the following trial. A *vegetable* coal will burn, on a red-hot iron, into white ashes, and these will be readily dissoluble by sulphuric acid into a bitterish liquor; whilst the ashes of *animal* substances are very sparingly affected by that acid, and form with it a compound having a very different taste¹. This fact is of importance to those sugar-refiners and others who use large quantities of animal charcoal in the state of powder, and which is often in danger of being adulterated with *vegetable* charcoal, an article that is not so efficacious, but is always to be obtained at a much lower price.

Charcoal is endowed with many singular properties, which cannot be too generally known, as some of them qualify it for rendering very important services to the arts. The intractable nature of carbon has been already mentioned; and whether coherent in charcoal, or in powder, is infusible by any heat that has hitherto been applied. "I have exposed it," says Sir H. Davy, "to the powers of intense ignition of different voltaic batteries; that of Mr. Children, one of 40 double plates of 18 inches square, and the battery of 2000 double plates of 4 inches, both in vacuo and in compressed gases, on which it had no power of chemical action. A little hydrogen was given off from it, and it slowly volatilized in these experiments, and the part remaining was much harder than before, so as in one case to scratch glass, and the lustre was greater; but its other properties were unaltered, and there was no appearance of fusion."—*Chem. Phil.* page 300.

It has been before mentioned, that charcoal is a bad conductor of heat; but I cannot avoid remarking that few persons, comparatively speaking, have availed themselves of this property, although there are innumerable instances in which charcoal might

¹ Lewis's *Commercium Philosophico-Technicum*, 4to, 1763, page 377.

be employed as a slow conductor of heat with very great advantage. The mention of a few of the most important of these must, however, suffice on the present occasion.

One of the most beneficial applications of charcoal, as a slow conductor of caloric, would be in some processes where it is necessary to preserve for a given time an equable temperature.

Thus, if all those vessels which are heated by steam, were made treble instead of double, and the space between the two outer vessels filled with ground charcoal, the heat would be so prevented from escaping, that any one particular temperature might be kept up for a great length of time, and a material saving of fuel would be accomplished. Guyton has shown that ground charcoal will conduct heat more slowly than even dry sand, and this in the proportion of three to two.

In extracting the colouring matter of dye-woods, and in making some other colours for the use of calico-printers, it is of great consequence to heat the vessels by steam; for by this mode of preparing decoctions the workmen are prevented from ever giving the materials a greater heat than that of 212° ,—and the injury which was formerly done by the grosser matters burning at the bottom and sides of the copper, is avoided. Several manufacturers have now adopted this method, and I have lately seen some apparatus in two or three establishments constructed on this principle, that appeared to me to be complete in every respect, excepting that they suffered much of the heat to escape; all of which might have been saved, and turned to a good account, by employing powdered charcoal in the way I have just described.

Again, whenever churches or other large buildings are to be warmed by steam, so much of the conducting pipe as is not actually within the building should always be surrounded in this manner: then no part of the heat could escape until it had been delivered within the space destined to be warmed by it.

In like manner, in the manufactories of starch, paper, gunpowder, Prussian blue, and a variety of other articles that might be mentioned, every part of the apparatus for drying these by steam, and which is not actually within the drying-rooms, ought to be secured in the same way.

The common steam-cooking apparatus and other culinary utensils would be much improved were they fitted with double covers, and the inner spaces between these covers filled up with charcoal-powder.

Moreover, by securing the conducting pipes in this manner, buildings might be effectually warmed, and processes conducted, at any distance from the side of the boiler, as “steam is the most faithful carrier of heat that can possibly be;” for it cannot deposit it on any bodies that have already acquired the temperature of 212° .

Owing to this non-conducting property of charcoal, it is very commonly employed in France to coat furnaces, and to confine the heat, for which its incombustible nature fits it in a peculiar manner¹, it being the most refractory body we know of, provided it be excluded from oxygen.

In domestic economy, charcoal is invaluable. From its property of retarding putrefaction it surpasses, as a preserver of meat, any thing we know of. Game, or any kind of animal food that has been over-kept, will be rendered perfectly sweet and wholesome by covering it with a few pieces of fresh burnt charcoal. Or, if it be far gone, boiling it for some minutes in water with a few ounces of such charcoal will effectually purify it².

How much better must the charcoal made in cylinders be for all these purposes than common charcoal! as the cylinder charcoal is free from the sap and acid of the wood, and consequently more tasteless in itself and lighter than the charcoal prepared in any other way. Those individuals who may be desirous of having such charcoal, may at any time procure it from the persons who manufacture either pyroligneous acid or gunpowder.

By its means also molasses or treacle may be deprived of its disagreeable taste, so that it might be used in families instead of sugar. M. Cadet Devaux says that he diluted twenty-four pounds of treacle with the same weight of water, and boiled it for half an hour with six pounds of pulverized charcoal, which entirely deprived it of its empyreumatic taste and smell. He then strained the saccharine liquid from the charcoal; and, having evaporated it to a due consistence by a gentle heat, found its flavour equal to that of good sugar. Those who have occasion to use honey, and yet have an objection to its peculiar flavour, may deprive it of this taste by a similar management.

The principle of refining sugar by means of charcoal is indeed the basis of the patent taken out by Mons. Cronstat, and for the transfer of which he required of the joint body of sugar-bakers in London a remuneration of fifty thousand pounds: and I have reason to think that the proprietors of a small concern established only a few years ago in the metropolis, where double loaves are manufactured of a finer quality than are produced at any other house, effect the purpose by the same means.

In like manner the disagreeable empyreumatic flavour which some brandies acquire in distillation, may be removed by digesting them on charcoal; and common malt-vinegar, if boiled on char-

¹ Fourcroy's *System of Chemical Knowledge*, vol. i. p. 248.

² That water impregnated with carbonic acid gas is such an effectual preserver of meat, is probably altogether owing to the carbon of which this acid gas is composed. An interesting letter from Sir William Lee, Bart. to Dr. Priestley on this subject, will be found in the Appendix to the fourth volume of the Doctor's "*Observations on Air.*"

coal, becomes quite colourless like distilled vinegar, without being impaired in strength; whereas it always becomes much weaker by distillation.

On the same principle charcoal is frequently employed by the manufacturing chemist in purifying any of the salts which may have become coloured from accidental circumstances, or from their combination with heterogeneous matters. It is only necessary to redissolve them, and boil their solutions on charcoal, and when re-crystallized they will be found pure and colourless.

Even the common salt of hartshorn (carbonate of ammonia), which is prepared from a liquor distilled from bones, and which often requires great labour to render it of the desired purity, loses the whole of its fœtid smell by being mixed with charcoal powder, and re-sublimed.

On long voyages the water, which has been laid in for the ship's crew, generally acquires a disagreeable taste and smell from standing so long in the wooden casks; but whenever this happens, it can be entirely purified by filtrating it through ground charcoal. It is always best, however, to send out water in casks that are charred within side, as water kept in such casks is always sweet. In London and elsewhere, it is very common to pitch water-casks on the whole of their inner surface; but surely it would be cheaper, and much more effectual for making them into good water-casks, to light a fire of wood-shavings within them, and keep it burning until the whole of the surface on the inside is completely charred.

It is difficult to understand how charcoal acts, so as to purify so many vegetable and animal substances, and to remove the colour and the noxious taste and smell of such a variety of articles, and in such a variety of states and cases; but as it has the property of absorbing all the known gases, and condensing them in its pores³ in quantities far exceeding its own bulk, to this the effect is probably due.

That these processes may always answer, it is necessary that the charcoal should be fresh made, or that it should be heated red-hot under a cover of sand immediately before it is used; and that in nice operations the necessary quantity should be ascertained by previous experiment: for, if too much be employed, the articles on which it is intended to operate will sometimes be decomposed, especially if heat be applied; and if a sufficient quantity be not taken, the effect will be produced only partially.

³ Some interesting disquisitions on this subject may be seen in the *Journal de Physique* for 1783; in the *Annales de Chimie*, tome xxxii.; in Murray's *Chemistry*, second edition, vol. ii. page 486; and in the 26th number of *The Journal of Science, Literature, and the Arts*, from M. A. Bussy's Memoir in the *Journal de Pharmacie* for June 1822.

M. Lowitz, who has pursued this subject further than any one else, has given some very important directions, which are necessary to be attended to by those who employ this substance as an article of purification in any manufacturing processes¹.

In some cases it is necessary to use it in a pulverized state; but in all these instances it should be pounded immediately from the fire, before it is exposed to the air; and what is not used should be preserved in glass bottles closely stopped, on account of the property it has, as we have already seen, of absorbing water and the gases in abundance.

In addition to the experiments of Messrs. Allen and Pepys, M. Chaptal has shown, that charcoal absorbs 15 or 20 per cent. of water from the atmosphere, while cooling, and that soft coke acquires 25 per cent. of water in the same time².

Besides those which have been already mentioned, charcoal has many other uses in the arts. It is used by mathematical instrument makers and engravers to polish brass and copper plates; by horners in polishing lanthorn-leaves; and by artists for tracing the outlines of drawings. On account of its powerful affinity for oxygen, it is employed by the makers of glass, by soap-boilers, and chemists, in decomposing the sulphates of soda and potash, so as to enable them to use their alkaline bases in the room of barilla. More of this, however, will be found in the second volume, in the Essays on the fixed alkalies and on glass.

Charcoal is employed also by the makers of *coloured* glass to communicate some peculiar tints of brown and yellow to their artificial gems. The late Mr. Samuel Moore, who was many years the Secretary to the Society for the Promotion of Arts, Manufactures and Commerce, made an extensive series of experiments on this subject. Some account of his processes may be seen in the "*Commercium Technicum*," published by his friend Dr. Lewis, page 628, &c.

In connexion with this subject, I am desirous of suggesting whether the tar which precipitates from pyroligneous acid, if judiciously employed, might not furnish these manufacturers with coloured glass possessing some original tints; for, on visiting an extensive charcoal-work, where the cylinders are erected within a very capacious building, I observed that the vapours which escaped during the distillation had coated the glass in the windows of a very lively colour between brown and orange.

On the Continent, it is a common practice to char one end of all the posts or other timbers which are to be fixed within the

¹ These directions will be found in Crell's *Chem. Journal*, vol. ii. pp. 165 & 237.

² Chaptal's *Elements of Chemistry*, vol. iii. page 199.

ground; and if this be carefully and properly done, and so much of the timber be charred as is to be covered with the soil, it will be rendered imperishable, or at least it will last much longer than the parts above the ground which have not been charred. Indeed charcoal is perfectly incorruptible if buried in the earth; therefore the deeper the surface of the wood is charred, provided enough be left to give sufficient strength to such posts, the more effectually will they be preserved.

This method of charring timber is already practised in some parts of England; and, being convinced of the economy and efficacy of the practice, I mention it here with the hope of rendering it more general. All that is necessary is to light a fire upon the ground, which should be surrounded with a wall built with loose bricks or stones, and then, when the pieces of timber are laid across the walls, to have a contrivance to turn them regularly round so as to present every part to the action of the fire in succession; and when the whole surface to the depth of three quarters of an inch or an inch is converted to charcoal they will be sufficiently prepared. While charring, they should have a temporary covering of green boughs or other matter to preserve them from the action of the atmosphere, which would be apt to convert part of the wood into ashes.

The incorruptibility of charcoal was well known to the ancients, and they availed themselves of this property on all important occasions. Of this we have abundant evidence.

In making the foundation for the temple of Diana at Ephesus, more than two thousand years ago, it was necessary to drive piles; and when some of these were taken up of late years it was found that they had been charred. Again, it has been stated that "about sixty years ago a quantity of oak stakes were found in the bed of the Thames, in the very spot where Tacitus says that the Britons fixed a vast number of such stakes, to prevent the passage of Julius Cæsar and his army. These stakes were charred to a considerable depth, had retained their form completely, and were firm at the heart³.

That it is actually possible to render wood indestructible, will appear from the recollection of the process of nature usually called petrification. About seventy years ago, one of the timbers that supported the bridge which the Emperor Trajan threw over the Danube a little below Belgrade, was taken up, and the outer part to the depth of half an inch was found to be converted to an agate, the inner parts were slightly petrified, and the central were still perfect wood, though this timber had been in the water 1700 years⁴.

³ Dr. Robison's *Introduction to Dr. Black's Lectures*.

⁴ Kirwan's *Geological Essays*.

There are few collections of minerals that do not contain some specimens of wood thus mineralized; and in the Emperor's collection at Vienna there are many pieces converted more or less into agates of various colours. Among them there are billets of half a foot or a foot in diameter thus petrified, and capable of taking a very fine polish. One of these is agate at one end, and retains its ligneous nature at the other.

In the History of the Academy of Sciences at Paris for the year 1763, is an account of Mr. Moll's cabinet of minerals, which is very effectual towards the conviction of those who deny the possibility of wood being thus agatized. The comparison which this eminent collector has made between certain woods and plants said to be petrified, and the same kinds of bodies in their natural state, seems to put this matter out of dispute.

Having made a large collection of wood that was converted into agate, he sawed off the thinnest laminæ possible from many of the pieces, and after polishing them he examined them by the microscope, and perceived plainly the difference of texture in the different specimens. It was observable that one of these was doubtless fir, another reed, or some aquatic plant of that class; and on examining shavings or small pieces of the wood to which he supposed the specimens belonged, it was impossible to resist the evidence furnished by this comparison. In both sets of objects the same direction of the longitudinal and transverse fibres of the wood is perceived, and the same arrangement of the vesicles¹.

In returning from this digression, it may be remarked that it were much to be wished that the English builders would adopt the practice above mentioned, and char every piece of wood before it is placed within the ground. Several years ago Dr. Watson suggested the propriety of charring all the wood used in mines and subterraneous drains, and particularly that employed in the covering of soughs, through which there is a current of water, and which rots in a few years by the alternate change of wet and dry². I would remark, in addition, that if this had been the general practice, many sad accidents which happen from the breaking of such timbers would have been prevented, and some lives saved.

Most of the houses in Venice stand upon piles of wood, which have all been previously charred for their preservation³. In this country, estates were formerly marked out by charred stakes driven to a considerable depth under ground.

¹ More on this subject may be seen in the *Appendix to the Monthly Review*, vol. xxxvi. page 557.

² Watson's *Chemical Essays*, London, 1789; vol. iii. page 48.

³ See Platt's *Jewel House of Art and Nature*, page 33.

It is perhaps worth mentioning, "that when old chesnut or other trees are rotted within the trunk, and threatened with speedy destruction by the progress of the carious taint, it may be stopped by applying fire to the decayed part, so as to char the whole of the neighbouring surfaces⁴. By this management the life of a favourite tree may often be preserved.

In enumerating many of the uses of charcoal, I have hitherto omitted to mention its employment in the manufacture of bar-iron, and the conversion of iron into steel; to the perfection of which, both the one and the other, wood-charcoal is, I believe, essential. Formerly, all the wrought iron that was made in this country was manufactured with charcoal; but as wood became scarce, and the Government restricted its use, the iron-masters gradually introduced the use of cinders and coke, and now most of the bar-iron which is made in these kingdoms is prepared chiefly by the latter methods. This, however, has reduced the quality of the English iron so much, that, for many purposes, the artificer is under the necessity of employing Russian and Swedish iron, which is all prepared by means of the coal of wood.

Mons. Hassenfratz is of opinion that the superiority of the iron which is made with charcoal, is owing to its combining with a portion of *potassium*; and when it is considered how great is the difference between iron and steel, and how small is the quantity of carbon that produces this difference, it may easily be believed that the potassium of the wood is capable of effecting the change in question⁵.

The ores of iron are very abundant in this country, and for some hundred years had been worked to a great extent for the production of this metal; and as nothing was at first used for the reduction of these ores but wood-charcoal, the consumption of wood became so enormous that the legislature thought it advisable to interfere, and prevent its indiscriminate use.

By the act of the 1st of Queen Elizabeth, chap. 15, it was enacted, that no oak, beech, or ash timber, of the breadth of one foot square at the stub, should be cut down to be converted to charcoal for making of iron, in any part of the kingdoms of England and Wales, except in the county of Sussex, in the weild of Kent, and in certain parishes therein named in the county of Surry.

Notwithstanding this enactment, the makers of iron gave up the use of charcoal with great reluctance, as they imagined that it was impossible to make useful malleable iron without charcoal.

However, about the middle of the last century some few iron-

⁴ See Chaptal's *Chemistry applied to the Arts*.

⁵ Nicholson's *Journal*, xxv. page 51.

masters acquired the habit of making bar-iron with the coke of pit-coal, prepared from a particular sort of coal, and in a manner which was kept secret from their competitors in the trade.

In the year 1773 Mr. Henry Horne published his "*Essays on Iron and Steel*," with directions for reducing the common iron ore, by means of coke, into pig-iron, and then into bar-iron, fit for the most curious purposes; and in the same work he gave directions for a more perfect method than any before known, of charring pit-coal so as to render it a proper succedaneum for wood-charcoal in the manufacture of iron. This little volume is now become scarce; it contains, however, many interesting particulars, and is, I think, worth the perusal of those who are engaged either in making iron or steel.

Since the publication of Mr. Horne's book, the coke of pit-coal has been brought into more general use, so that at this day many thousand tons of coal are annually converted into coke, not only for the purpose of making iron, but for various other employments connected with the trade and manufactures of the country.

The coke of pit-coal is used largely in the drying of malt, and in the fires of a variety of artists, to whom the smoke of pit-coal would be injurious; in refining gold and silver; and in the smelting of metals. In the preparation of this coke, the fuliginous, bituminous, and sulphurous parts of the coal, which would give a taint to the malt, and a brittleness to the metals, are dissipated, whilst the more pure and carbonaceous matter is left¹.

The consumption of coke is now so considerable, that within these few years great attention has been paid to the selection of the best kind of pit-coal for its preparation, and to the improvement of the ovens in which the operation is performed. Those in the neighbourhood of Sheffield, belonging to the Duke of Norfolk, are the best which I have seen².

It has been usual in the large iron-works to prepare the coke without ovens, merely by making large piles of common coals in the open air, somewhat similar to that mode of making wood-charcoal described at page 163, and setting fire to these heaps at different places at the same time; and when the mass appears to be thoroughly lighted, to cover, or smother up as it is called, the whole heap with dust. In this state the combustion is continued until all the coal is converted into coke.

A new method of making coke has, however, of late years

¹ See some further observations on this subject in Lewis's *Translation of Neumann's Chemical Works*, vol. ii. page 277.

² A very particular description of these ovens will be found in the Additional Notes to the *Chemical Catechism*, No. L.; and also in the description of the plates to the present volumes.

been adopted at an extensive iron-work in the neighbourhood of Chesterfield, which has been found very advantageous.

For this purpose a substantial brick-chimney is built on an open space of ground, and the coal is piled round it. When the pile is constructed, instead of lighting it in different places on the outside of the heap, a quantity of ignited coal is thrown down this brick-chimney; which being built upon arches, the fire readily communicates through them to those parts of the pile which are immediately contiguous to the chimney, so that the fire commences in the *middle* instead of at the *outside* of the heap, and soon spreads through the whole mass. When sufficiently burnt, and partially cooled, the heap is broken into, and the whole is quenched by water.

The coke thus prepared is so much better than that which is produced in the common way, that a less proportion of it is sufficient for making any specific quantity of iron.

This enables the blast-furnace to hold an additional charge of iron-stone, and consequently the manufacturer can run considerably more pig-iron at every operation. The annual saving which this has occasioned is, I understand, far exceeding that which the proprietors themselves had expected; for, the quantity of the coke produced is much greater from a given measure of the coals, and, what is of still greater importance, the iron is of a much better quality.

The proprietors of these works, who deem this new method of coking to be a most important improvement in their manufactory, consider the cause to be totally inexplicable.

To hazard a conjecture respecting the nature of this obvious improvement, I should certainly attribute all these advantages to the chimney, which from the nature of its construction occasions a constant draught of air through the whole body of the burning materials, and carries off all the gaseous products which would otherwise be absorbed by the coke, and impair its quality; similar to the injury which the wood-charcoal received by stopping up the vent-holes, as related at pages 167—169 of this volume.

Having given an ample account of the preparation of charcoal, and of the uses to which it is applied, and also of the various compounds which have been formed by its means, it will now be proper to speak of the principal *natural* productions which contain carbon as one of their component parts.

Of these we have native mineral carbon and carburet of iron, besides the diamond already treated of; and a great variety of minerals containing carbonic acid as one of their component parts, such as carbonate of lime including chalk, limestone mar-

ble, calcareous spar, slate spar, satin spar, lucullite, and several others; of some of which there are vast mountains in various parts of the world; Witherite, or carbonate of barytes; strontianite, or carbonate of strontites; natron, or carbonate of soda, besides others which might be mentioned: but, as it would extend this Essay to too great a length to describe all these productions of Nature, I shall content myself with offering a few remarks on some of the varieties of mineral coal, of all which the basis is carbon.

Mineralogists in their classification of coals have divided the whole into four species, very distinct from each other; viz. *plumbago*, or the *graphite* of Werner, which is a carburet of iron; the *anthracite* of Haüy, or, as it is more commonly called, *anthracolite*; jet and cannel coal; and all the varieties of common pit-coal.

Plumbago, usually known by the very improper name of black-lead, occurs in some particular spots in most countries in the world. It is well known as the article of which pencils are made¹, and is found in various situations, such as in the midst of mountains, in beds of quartz, and in masses of calcareous earth. It generally occurs in kidney-form lumps of various dimensions from the size of a pea to pieces of some considerable weight. Its specific gravity is about twice that of water; though Dr. Freind states it to be only 1.714, and Boyle 1.860. When pure, it consists of about ninety-five parts carbon and five of iron. Hence, as might be expected, it is as incombustible and indestructible as charcoal, unless heated with atmospheric air²; there is, however, considerable difficulty attending the analysis of this mineral, from certain causes which have been pointed out by Mr. Brande³. Some kinds of *plumbago* are very impure. Vauquelin has given the analysis of a French specimen which contained only 23 per cent. of carbon, 2 of iron, 38 of silica, and 37 of alumina.

To the modern methods of analysis we are entirely indebted for a knowledge of the nature of this substance. Camden, our celebrated historian, calls it “a metallic earth, or hard glittering

¹ From a remark of Sir John Pettus, I imagine black-lead pencils have not been in use more than 150 or 160 years. “*Of late*,” says he, speaking of black-lead, “it is curiously formed into cases of deal, or cedar, and so sold as dry pencils, something more useful than pen and ink.” Sir John Pettus’s *Fleta Minor*, folio, London, 1686, article *Lead*.

² It is this property which renders *plumbago* one of the best substances in nature for the fabrication of those crucibles which are designed to resist the most intense heat.

³ Brande’s *Manual*, vol. ii. page 121.

stone, used by painters to draw with. "Whether," says he, "it be *pnigitis*, or *melanteria* of Dioscorides, or ochre burnt black by the heat of the earth, I cannot determine⁴."

Boyle calls it "a mineral *sui generis*, approaching to a talc," and says that "it has nothing metallic in its nature⁵." The ingenious Scheele was the first person who pointed out the real nature of this mineral. He showed that by burning it in a peculiar manner it might all be converted into carbonic acid gas, except a small residuum, which he found to be iron⁶.

The finest plumbago that has ever been discovered is procured from a mine at Borrowdale, about six miles from Keswick, and in the neighbourhood of the lofty mountain of Skiddaw, in the county of Cumberland. I know of no other mine which produces this mineral in a state fit for making good black-lead pencils: it is on account of its excellency therefore exported to all parts of the world⁷. The superior quality of this article is indeed so generally allowed, that on the Continent the pencils made with it are called *crayons d'Angleterre*.

Plumbago has within these few years been found of tolerably good quality, and in very considerable quantities, in an estate lying about seven or eight miles north of the town of Ayr in Scotland. In some parts of that neighbourhood it occurs at the surface of the ground. It has been discovered also at a considerable depth at the foot of the mountains in the island of Ceylon⁸.

Dr. Campbell, in his Political Survey of Great Britain, speaking of the Borrowdale mine, says that this mine is private property, that it is opened but once in seven years, and no greater quantity than is equal to the consumption is allowed to be sold. At the mine it is called *wadd*, and those who are concerned in raising it suppose it to be impregnated with lead and antimony. Dr. Campbell considered it to be a mixture of talc and zinc⁹. When this mineral was first raised, it was employed for marking sheep. It was afterwards used in medicine, for disorders of the bowels, and in nephritic complaints¹⁰.

Although the mine at Borrowdale may alone produce plumbago fit for making the best sort of pencils, there are many other

⁴ Gough's edition of Camden's *Britannia*, folio, vol. iii. 170.

⁵ Boyle's *Works*, vol. v. page 27.

⁶ Scheele's *Chemical Essays*, page 243.

⁷ According to Dr. Campbell, this mineral is used with great success by dyers in fixing blue colours, vol. ii. page 38.

⁸ Cordiner's *Description of Ceylon*, 4to, 1807, vol. i. page 13. Knox's *History of Ceylon*, folio, page 31.

⁹ *Political Survey of Great Britain*, London, 1774, 4to, vol. ii. page 37.

¹⁰ *Philosophical Transactions*, No. 240, page 183.

places where this mineral is to be found, and sufficiently good for all other purposes. At present it is applied chiefly to the following uses.

It is employed to make crayons and black-lead pencils; to cover the best sort of iron castings to give them a shining coat, and preserve them from rust; to give a polish to small leaden shot; to rub on the cogs of wheels and other machinery, in order to diminish friction, and impart smoothness and lubricity to the parts which have most wear; to mix with potter's clay for the production of some particular sorts of earthenware; to make crucibles and other utensils which are to undergo intense heats; and, when kneaded with clay, to line all sorts of portable furnaces which are designed to be used in the reduction of ores and other chemical operations.

The natural incombustibility of plumbago peculiarly fits it for other purposes to which it has not yet been applied in this country; but especially for the covering of certain parts of wooden buildings to preserve them from accidents by fire.

It is lamentable to perceive with what facility and success some people impose upon the public. Even the article of plumbago has been employed for purposes of quackery. The following is the substance of the specification of a patent, dated the 6th of June 1812, for what the patentee calls his "Anti-Attrition Paste." It is merely that 1 cwt. of plumbago be mixed with 4 cwt. of pork-lard, or with a like quantity of suet, or of some one of the other articles enumerated in the specification¹. Surely this patentee could not be ignorant of the fact that such a mixture had been long used for similar purposes prior to the date of his patent, particularly in many of the manufacturing counties. In order, however, to expose this pretension to originality the more effectually, the following recipe is selected from a printed volume, which may be had of any of the principal booksellers in London or elsewhere. "Mix one pound of hog's lard with half a pound of black-lead; stir them well together, whilst melting over a slow fire. If the axles and bushes of the wheels be true, a carriage may safely be run one hundred or one hundred and fifty miles, with once using the above composition²."

Some time ago, a gentleman, a native of the state of North Carolina, informed me that a mine of black-lead had been discovered in the neighbourhood of Raleigh, one of the cities of that state, which promises to be of very considerable consequence to the whole of North America. The mineral occurs in large solid lumps, and the mine is so extensive that it is thought

¹ See *The Retrospect*, No. 34; or *The Repertory of Arts*, No. 130.

² *The Family Receipt Book*, Murray, London, 1811, page 414.

to be inexhaustible. It is usually sold in its native state, packed in barrels, at 18s. or 20s. per cwt.

This native carburet of iron is used very extensively in the state of North Carolina for a variety of purposes. They grind it with oil for painting the wooden roofs of their houses and even their best buildings. It is found to answer extremely well for preserving the wood from decay, and for keeping out the rain; and it is a great preservative against fire.

In America, where most of the fires are made with wood, accidents often happen from the circumstance of the sparks setting fire to the wooden roofs of their houses, and occasioning dreadful conflagrations: but this can never occur to those roofs which have been treated in this way; for I learn that the wooden shingles, which have been painted with two or three coats of this preparation, have been purposely exposed to the full heat of a large fire for a considerable time, without their sustaining any injury.

This seems rather extraordinary, as one would have imagined that the oil would have still retained its combustible properties. It may, however, be a circumstance well worth the investigation of those who have it in their power to procure plumbago at a cheap rate.

On a journey to the lakes of Westmoreland and Cumberland, in the summer of the year 1814, I heard that the celebrated mine of black-lead in Borrowdale had been lately opened, and that the workmen were then engaged in raising and dressing the mineral. Rejoiced at this intelligence, I immediately determined not to lose so favourable an opportunity of visiting this curious spot, and therefore fixed myself at Keswick, the nearest town to the mine, in order to collect the necessary preliminary information, and learn how to procure the most intelligent guide which the neighbourhood could afford. In travelling from the north, the road lies thus:—From Carlisle to Wigton 11 miles; from thence to Keswick 22 miles; and from Keswick to the mine 9 miles. From Keswick to the mine saddle-horses are necessary, as some of the defiles through the mountains are too narrow to admit the passing of a carriage. As no account has hitherto been given of this celebrated mine, where black-lead is found of a quality far superior to what is known in any other part of the world, I trust the following particulars will not be uninteresting to my readers.

The neighbourhood of Keswick has for ages been celebrated as a mining country. In the reign of Queen Elizabeth, gold and silver were procured in considerable quantity from the mountain called *Gold-scarpe* in the vale of Newlands near Keswick. At that time the mine was worked by a company of Germans, who

raised a large quantity of copper and lead, and not only converted these to their own use, but also laid claim to the precious metals, in opposition to the Queen, who demanded them as well as the usual royalty. However, on an appeal to common law, her majesty gained the point, and the foreigners soon after absconded.

It was during this reign that the very valuable mine of black-lead was discovered. The inhabitants of the neighbourhood say that this rich depository was first brought to light by a tremendous hurricane, which blew up a large ash-tree and discovered a mass of fine plumbago at its root. The mine now at work is in the midst of a mountain which chiefly consists of slate and that species of rock called *grauwacke*; it is about 2000 feet high, it rises at an angle, as near as I could guess, of 45 degrees, and is situate among other stupendous hills in a district known by the name of *Borrowdale*. When the value of this mine became known, the proprietors found it very difficult to guard it so as to prevent depredations. The practice of robbing it was become so common, that several persons living in the neighbourhood were said to have made large fortunes by secreting and selling the mineral: this, however, is now entirely prevented by some expedients hereafter to be mentioned. Even a guard stationed on the spot was of little avail, for 70 or 80 years ago a body of miners broke into the mine by main force, and held the possession of it in spite of the proprietors themselves. At one time the depredations had arrived to such a pitch, and so great was the quantity which had been stolen, that the delinquents were actually able to deprive the proprietors of their regular customers, by lowering the price of the article in the London market. This circumstance so annoyed the original company, that at last they thought it expedient to buy up the whole stock that remained in the hands of the robbers, as the only way of putting an end to the competition. It is not many years since a very large quantity of fine black-lead was found on Vickers Island, situated in Derwent-water; and it is supposed that this was secreted there at the time the robbers had possession of the mine in Borrowdale.

It has been already mentioned that the black-lead mountain has an altitude of about 2000 feet; and as that part of the mine which is now working is near the middle of the mountain, the present entrance is about 1000 feet from its summit. There are indeed two entrances; a small one by which the workmen descend by means of a flight of steps; the other is a large horizontal one capable of admitting hand-carts and wheel-barrows for the removal of the rubbish and loose earth by which the black-lead is enveloped; and through this entrance the water passes off which constantly runs through the mine.

In order to secure the vast treasure which is contained within this mountain, the proprietors have now erected a strong brick building, consisting of four rooms on the ground-floor, one of which is immediately over the opening by which the workmen enter the mine as they go to their work. This opening is secured by a trap-door, and the room connected with it is called the dressing-room; for, when the men enter it, they strip off their usual clothes, and each of them puts on a dress suitable for working in a mine. The men work six hours each, and then they are relieved by others. When the hour of relief comes, the steward attends in the dressing-room, to see the men undress, as they come up the steps one by one out of the mine, when they put on their usual clothes, which are also examined by the steward to see that they have no black-lead concealed within them. This room contains no furniture except the pegs on which the clothes are hung, and which extend all round the room, each man knowing his own. When these have dressed and departed, another set of men clothe themselves for their work and enter the mine as before; the trap-door is then again shut, and the steward is relieved to attend his other occupations.

I have said that the house consists of four rooms, and these are contrived so as to be connected with each other. In the innermost of these rooms there is a kind of counter or strong table, under the window, at which two men sit who are constantly employed in assorting and dressing the mineral. This is necessary, because it is usual to divide the black-lead into two kinds, called best and coarse; and as the finest specimens have generally pieces of iron-ore or other impurity attached to them, these are dressed off by peculiar tools adapted to the purpose. These men are constantly shut in when at work, and the steward walks backwards and forwards in an adjoining room furnished with two loaded blunderbusses, which hang within his reach, for the sake of further security. As the black-lead is cleaned, it is put into firm casks which hold about 112lb. each, and these are sent by waggon to the warehouse of the proprietors in London. Formerly this mine was opened only once in six or seven years, as I have before said; but in consequence of the demand being greater, and the quantity which they have discovered not being so large, it has been found expedient to open the mine, and dig for the ore during six or seven weeks in every year. At this time the mine is guarded night and day; and it is thought necessary that the steward, who only lives at the village of *Seathwait* at the foot of the mountain, should not leave the house at any time during the whole of this period, except an hour or two on the Sunday to visit his family, and even then, as he told me, he was always careful to return to his dwelling on the mountain while it was yet

day-light. In consequence of the mine having of late years been opened every summer, they now raise all the black-lead they find, and then the mine is securely shut up in the following manner:—The workmen wheel back the rubbish which had been removed at the opening of the mine, and this is laid in one continued heap, to the amount of some hundred cart-loads, which securely blocks up both the passages into the mine. The door is then locked, as well as the door into the house, and all the men then leave the premises in a state of safety; for the mass of rubbish which is thus wheeled in at the larger door, dams up the small rill of water which usually flows through the mine, and this has the effect of flooding it completely. Thus, if an attempt were made to break the house and enter the mine by that road, the robbers would find that the water had arisen to such a height as would drown any individual who should attempt to search for the ore.

From an examination of the exterior of the mountain, it appears that in former times various small shafts have been sunk for getting the black-lead; and the mine which they are now working was one of those which had been closed for a century, but was again opened in the year 1769, in consequence of another mine in the immediate vicinity having failed. The expense of raising the black-lead varies very much in different years, according to the size of the masses which the workmen happen to meet with: for instance, that which they found in the year 1778 was four yards in diameter, and twelve yards high; that of 1803 was twenty-one yards and a half high, two yards and a half in diameter, and perfectly round like a column; that which they found in 1812 was rather less than twenty yards in height, and only two foot in diameter; and what they are now getting is found only in a narrow string. The expenses of driving the level, of building the house, and working the mine, from the 23d of April 1798 to the 4th of April 1814, have amounted to 6637*l.* 9*s.* 4*d.*; and during this period there have been produced 736 casks of fine black-lead, and 1816 casks of the coarse kind, amounting together to 2552 casks of about 112*lb.* each.

It might be a matter of difficulty to those who visit the mine, to conceive how these casks of black-lead can be conveyed with safety down the face of so steep a mountain. This is done by men who have been long accustomed to the task. The cask is fixed upon a light sledge with two wheels, and the man, who is well used to this sort of precipitous path, walks coolly down before the sledge, taking care that it does not acquire too great a momentum, and thus overpower him. The empty sledge he then carries back upon his shoulders, and takes another cask. All the black-lead is sent to London, as I have already mentioned, where it is deposited in the warehouse of the proprietors, and

afterwards disposed of by public auction held at Essex-street in the Strand, London. This happens on the first Monday of every month throughout the year; and the best kind usually sells for two guineas or more per pound. There are some considerable manufactories of pencils at Keswick, but I was told that the makers are under the necessity of sending to London for all the black-lead they use in the trade, although they reside so near the place of its production.

The propriety of this valuable mine is divided, as I understand, into two equal parts, one of which belongs to Henry Bankes, Esq. member of parliament for Corfe Castle; and the other moiety is divided into ten or twelve shares belonging to the executors of the late Sir Joseph Banks, Sir John Mitford, and others. In some years the net produce of the black-lead has amounted to thirty or forty thousand pounds. Mr. Otley has stated, that by an account drawn up in 1804 the stock of black-lead then on hand was valued at 54,000*l.*, and the annual consumption about 3500*l.*; the best black-lead was then sold at 35*s.* per pound; since that time the price has been from 30*s.* to 45*s.* and the consumption is much increased. It is remarkable that this mine, which was valued in making the grant of the manor of Borrowdale by King James I. at 15*s.* 4*d.*, was on the last assessment for the property tax, estimated at 2700*l.* sterling a year. Some other particulars respecting this singular mine may be seen in the works quoted below¹.

The second kind of coal, which is called anthracolite, is seldom found but in the primitive mountains. It is generally amorphous, but sometimes occurs in a crystallized form. It is what is called incombustible coal, and by Werner glance-coal; and as it contains more carbon than most of the common pit-coal, it may with propriety be classed next to plumbago. It burns slowly and without flame; its specific gravity varies from 1300 to 1500. This species, which is composed of 64 carbon, 33 silica, and 3 parts of iron, is considered by some mineralogists not to be of vegetable origin.

The third kind of coal mentioned above, is jet and cannel coal. Both these varieties Werner denominates by the name of *black coal*. They are found in many parts of the world, and are often used in forming ornamental trinkets, particularly in France, where they occur in abundance.

¹ Robinson's *Natural History of Westmoreland and Cumberland*, 8vo, London, 1709, page 75; Colonel Thornton's *Sporting Tour through the Northern Parts of England*, 4to, London, 1804, page 282; Mr. Otley in *Memoirs of the Literary and Philosophical Society of Manchester*, second series, vol. iii. pp. 168—175.

The cannel coal does not cake in the fire; and though it flames like a candle in the beginning of its combustion, this lasts but for a short time, and the residuum is considerable. Its specific gravity is from 1.234 to 1.250. A specimen of the Lancashire cannel coal analysed by Mr. Kirwan, contained 75 per cent. carbon, 22 maltha, and 3 alumina and silica.

The fourth species includes all the varieties of the common pit-coal. These are composed of bitumen, carbon, and heterogeneous matters in different proportions, according to the places from whence they are procured. Some of these are black and ponderous, and, from the quantity of bitumen and sulphur which they contain, burn very freely, and give out a great heat, though the combustion is of short duration. This sort generally contains a large admixture of martial pyrites, which sometimes occasions spontaneous combustion when they are laid in large heaps, and are exposed to the affusion of water.

There are other coals that burn very freely, which cake into a mass when laid on the fire; these burn without any sulphureous smell, and leave no residuum but a very inconsiderable quantity of ashes.

Respecting the specific gravity of coals, the accounts which I have seen vary in themselves as much as they do from the results which I obtained. Mr. Charles Labelye makes the specific gravity of Newcastle coal to be 1.270. Boyle gives the specific gravity of Scotch coal 1.300. The Oxford Philosophical Society states the specific gravity of pit-coal from Staffordshire to be 1.240. Mr. John Caswall makes the same coal to be 1.238. The Philosophical Society at Oxford found a cubic foot of pump-water to be $62\frac{1}{2}$ pounds avoirdupoise; the same measure of Staffordshire coals 63 pounds; and of Newcastle coals 67lb. 12oz¹. Kirwan gives the specific gravity of six species of coal which vary from 1.232 to 1.357. A specimen of slate-coal he found to be as high as 1.426².

There is a peculiar kind of hard coal raised at Pontetaive, a few miles from Swansea, which is much approved by those who are afflicted with some kinds of pulmonary disorders; for it burns like coke, and yields no smoke. It does not soil the fingers, and the chimneys seldom or never want sweeping. In consequence of this, many persons troubled with asthma have taken up their residence in that neighbourhood.

There is a very singular kind of coal, as I have been informed, found in some parts of Pembrokeshire, called *stone-coal*. This coal is so devoid of sulphur that it is commonly employed without

¹ See *Philosophical Transactions*, No. 169.

² Kirwan's *Mineralogy*, vol. ii. page 514—528.

being previously coked, even in the operation of drying malt, for which purpose either wood-charcoal or coke is usually employed. The small of this coal is known by the name of *culm*, and is exported in large quantities from Milford Haven, for the particular purpose above mentioned. The inhabitants of the county where this mineral substance is found, are in the habit of making the culm into balls with clay and water, and laying these up for their winter's consumption. The inhabitants of Pembrokeshire have also a very singular way of using this fuel. When a fire of the large coal has burnt up, a quantity of the culm mixed with clay and water as above mentioned, is plastered over the whole of the fire, of the thickness of three or four inches; and then having made two holes with a poker through this plaster, for the purpose of keeping up a proper draught, it will preserve a good fire, of a perfect glow, without flame or smoke, for 12 or 14 hours.

Hugh Platt in his "Jewel House of Art and Nature," first printed in the year 1594, offers to sell a receipt for making fuel for the poor, which he says will prove more durable and much cheaper than coals. A copy of this work, which is now extremely rare, I had an opportunity of consulting at Chetham's library, in the College, Manchester; and from minutes made in this copy it appears that a Mr. Gosling, merchant of London, disclosed the said method gratis in the year 1628, and was at the expense of printing hand-bills to be distributed in every parish in London and its vicinity, to direct the poor how to make the said fuel. One of these printed hand-bills is attached to the volume above mentioned, from which I have copied the following directions, in the hope of their being useful. "Get," says Mr. Gosling, "a load of stiff loam or clay, and take half a peck of it, and with a shovel make it soft with water, then put one peck of small coal to it, and incorporate or mix them all together until you may roll it or mould it into several parts like pieces of charcoal or long eggs. As many may be made in a day as will last a quarter of a year. Any other combustible may be mixed up with it, such as peat turf, saw dust, curriers' or shoemakers' shreds, tanners' waste bark, and such like." It is added in a note, that "he has dispersed freely many thousands of these hand-bills for the good of all people in the land."

In some districts, coals are raised which have more the appearance of slate or schist than coal, and which only burn in consequence of the bitumen with which they are impregnated. These leave a bulky and stony kind of residuum, and are very unprofitable for most purposes.

There are other pit-coals which are so intimately mixed with sulphuret of iron that they become decomposed by the action of the air, and fall into dust, or what is called very small slack.

Such coals are fit only for heaping upon large fires, for the burning of limestone, or the preparation of coke.

The decomposition of such coal by the accession of water is no doubt the origin of the hydrogen gas, or what is called the coal-damp of many of our collieries, and which often occasions deplorable accidents.

In Lancashire, the workmen get rid of this gas by sending down one of their party to set fire to it, which he does with safety to himself by lying flat upon the ground, and letting it explode over him; but this is a method which could not be practised in some districts with safety.

A method of clearing a coal-pit of the coal-damp, by making a fire and fixing pipes to occasion a circulation, as described by Sir Robert Moray more than a century ago, may be seen in the *Phil. Trans.* vol. i. page 79, accompanied with a drawing of the whole of the apparatus.

The situations in which coal is found are as various as the composition and properties of the several species of coals themselves. Our deepest mines are in the counties of Durham and Northumberland, and the thickest beds are found in Staffordshire. The most productive vary from 8 to 10 yards, and one was found near Wednesbury of the enormous thickness of 16 yards. In the counties of Gloucester, Worcester and Stafford; at Newcastle-upon-Tyne; in the neighbourhood of Sunderland; and in many other parts of the kingdom, the coal is raised from very considerable depths; but in the vicinity of Stainthorpe, in the county of Durham, nothing more is necessary than to pare off the turf, and dig out this valuable production at the surface of the ground.

This coal is of excellent quality, much superior to that which is raised in Northumberland for the supply of the London market. If a rail-way were made from Stainthorpe to Stockton-on-Tees, a distance, I believe, of not more than 20 miles, this coal might be conveyed thither at a small expense, and from thence coastwise to London, to the great advantage of the metropolis, and to the enrichment of the district from whence it is to be procured.

A very singular kind of coal is found near the village of Seaton, in the neighbourhood of Hartlepool, in the county of Durham, which is brought up by the tide, and that only occasionally. It is in the form of very coarse sand, the grains of which are so polished that they may be handled freely without soiling the hands, and yet they are so small, that it would be difficult, among a large heap, to find a piece larger than a cherry-stone.

This coal, which abounds with bitumen, and consequently makes excellent fuel, is generally left by the tide on the sea-shore,

in a continued ridge, extending sometimes from a quarter of a mile to a mile in length, three or four inches thick, and only of a few feet in width.

As a considerable time often elapses between the periods when these supplies arrive, a very interesting scene is exhibited whenever one of these strata is thrown up by the tide. In an instant, as it were, all the inhabitants of the village hasten down to the shore, and are seen busily employed in raking it together, and in carting it away before the return of high water, which would wash all that remained off the shore.

Thus, by the bounty of Nature, are the poor of the whole neighbourhood supplied with an article of the first necessity; and merely by a little industry in the summer months are they enabled to lay up an ample store of excellent fuel for the whole of their winter's consumption.

Among the inflammable substances of the mineral kingdom may be classed what is called *elastic bitumen*, or mineral *caoutchouc*, a fusible and very singular substance found in the Odin mine, near Castleton in Derbyshire. It has been fully described by Mr. Hatchett¹, as a compound of carbon, bituminous oil, carburetted hydrogen gas, &c.²

Retinasphaltum is another peculiar inflammable body which occurs in the Bovey coal of Devonshire. It is a substance which seems to connect the resins with the bitumens. It was first analysed by Mr. Hatchett³, and found to consist of 55 resin, 41 asphaltum, 4 earthy matter, &c. = 100.

Mellilite is a rare substance that sometimes is found in the brown coal of Arten in Thuringia, and also in Switzerland. It is of the colour of honey, and from this circumstance was named by Werner honey-stone. It occurs crystallized in octohedrons. Its surface is smooth, it is translucent, and doubly refractive. Its specific gravity is 1.666. According to Klaproth it is a compound of a peculiar acid, which he named the mellitic acid, 46 + alumina 16 + water 38 = 100. By proper evaporation of the solution, the acid may be obtained in crystals. M. Klaproth seems to have analysed the mellilite, and also its acid, with great care⁴. Vauquelin has likewise published a distinct paper on the mellilite, in which he confirms the analysis of Klaproth⁵.

It may not be irrelevant to remark, that if a line be drawn upon the map of England across the country from Sunderland

¹ Scherer's *Journal*, No. 21, page 282.

² Klaproth's *Essays*, ii. page 87.

³ Hatchett, *Philosophical Transactions* for 1804.

⁴ Klaproth's *Analytical Essays*, vol. ii. page 89—105.

⁵ Vauquelin, *Annales de Chimie*, xxxvi. page 203—214.

to Bristol, all the counties on the west of this line will be found to contain coal¹. Formerly these counties were the least valuable districts, and the parts of the country which were the most thinly inhabited. Hence, when the constitution of the British Parliament was established, the greatest weight of representation was given to the rich counties which were on the other side of that line. The 12 English and the 12 Welch counties, lying on the western side, send, together, only 114 members to the British Parliament; whereas the 28 eastern counties return 399 members. Whereas, now, owing to the establishment of manufactures, the coal-counties have become the most populous and wealthy, and the agricultural districts have either been comparatively deserted, or at least have not much increased in population.

This, in my opinion, accounts in some measure for the inequality of our representation, and shows, very distinctly, the value of our mines of coal, and that by the establishment of manufactures, even the most sterile and forbidding country may be rendered populous, flourishing and opulent. The consequences of the establishment of manufactures have been peculiarly striking in some parts of Austrian Flanders. The industry of the inhabitants of Brussels has been such, that an acre of land in the environs of that city will yield in manufactures an amount equal to the revenues of the whole province of *Champaigne*.—Carrard *On the Spirit of Legislation*, page 313.

To the patient and unremitting industry of our mechanics, and the frugality of their habits, we are beholden for our success as a manufacturing people². Unlike many of the nations of Europe, who through indolence or inattention suffer the richest treasures of Nature to remain undisturbed in the bowels of their respective countries, it has become a custom among us to husband all our resources, and to appropriate every thing, even down to the very residuums of our manufactories, to some useful purpose.

To what degree of excellence our manufacturers and mechanics may arrive in the economy of their materials, when chemical science is better understood by them, and when a knowledge of her laws is more generally diffused, it is impossible to conceive; but this is the point in which we are most deficient, and this is the important desideratum which every person who has any influence in the country should do his utmost to supply.

¹ Coals are also found plentifully in Scotland; but a line drawn on the south of the Tay from the bank opposite to Dundee, along the Ochil hills to Stirling, is esteemed the northern boundary of the coal of this island.

² I have read of an Emperor of China, who, when he was about to suppress the monasteries of bonzes, declared aloud to the mandarines of the nation, that if he had a man that did not labour, or a woman that did not spin, he was sure some one must suffer cold or hunger in the empire.

ESSAY VI.

ON THE MANUFACTURE OF BRASS.

OF all the numerous metallic alloys at present known, that of copper with zinc is by far the most important and generally useful. This compound, which in common language is called *brass*, is of high antiquity, for we read of it in the very earliest period of sacred history, where Tubal-cain is described as “an instructor of every artificer in *brass* and iron¹,” and in a subsequent book, that “Moses made a serpent of *brass*.” It has indeed been asserted, by some writers of great credit, that brass is a modern invention; but they surely must allude to the mode of manufacturing it, and not to the alloy itself; for the late Bishop of Llandaff and other respectable authors have stated, that the *orichalcum* of the Romans resembled our brass in all respects, and was composed of the same materials. My principal object, however, in this paper is, to give a detailed account of the methods by which brass is now made in this country, having, on a late occasion, and for this particular purpose, minutely examined one of the most extensive works in Great Britain, where the only article of manufacture is that of brass.

It is well known that it is difficult to unite zinc in its metallic state with copper in the direct way, the former being readily oxidized at a high temperature, occasioning considerable loss. Some ores of zinc, particularly *calamine*, an impure carbonate of the metal, is therefore chosen, having been proved to answer every purpose. This mineral is found plentifully in the Mendip hills in Somersetshire; at Wirksworth and Bonsal-moor in Derbyshire; also in North Wales and at several other places in Great Britain. As this ore is never so pure as to be employed in its crude state, it is necessary that it should undergo the processes of washing, calcination, grinding, and sifting, before it can be fit for making brass.

The copper which is employed in the manufacture of this metallic alloy is previously granulated by being poured in a melted state into water. The method of preparing it is as follows:—

The product of what is called the *roaster furnace* of a copper smelting work, generally consists of from 90 to 92 per cent. of copper, the remaining 8 or 10 per cent. being iron, lead, tin, sulphur, or other matter accidentally present in the ores from

¹ Genesis iv. 22.

² Numbers xxi. 9.

which it was reduced. This compound having been cast into masses called *pigs*, is, to the amount of a ton and a half to three tons, put into a furnace of the reverberatory kind called the *refinery*. The floor or hearth of this furnace is made of clean sea-sand, the grains of which are agglutinated together by heat; it is laid with an inclination from the bridge to the mouth of the furnace, opposite to which a small pool or basin is formed in the floor, so that the depth of the copper, when melted, may be always sufficient, in that place, to allow the workmen to fill their ladles when lading it out for the granulating operation.

The furnace being charged with pigs as above mentioned, the door in front is closely luted, and heat applied sufficient to melt the metal; and when the whole is in perfect fusion, the following changes will be found to have taken place. The sulphur will have passed off in the state of sulphurous acid gas, and the iron, tin and lead will have become oxidized; which oxides, together with any sand that adhered to the pigs from the moulds in which they were cast at the roaster-furnace, will have melted into a slag or glassy scoria, holding a portion of oxide of copper, which imparts to it various tints of red, purple, &c.

This slag, in consequence of its inferior specific gravity, swims on the surface of the melted copper, and is skimmed off with an iron rake or *rabble* as it is technically called.

The refiner, in order to be certain that the afore-mentioned changes have taken place, takes out of the furnace a small quantity of the copper called an *assay*, and when this is cold he cuts it half through with a chisel, and completes the separation by breaking it in a vice. If it is brittle, and the fracture exhibits a deep red colour, and a fibrous, or rather a hackly structure, the copper is in a proper state for lading into the water, which is done in iron ladles coated with clay, and holding from 25 lbs to 30 lbs. each of the melted metal. By this treatment the copper is broken into granular pieces from the size of small shot to that of a horse-bean.

It has already been remarked that the calamine, which is designed for making brass, undergoes a previous calcination; but preparatory to its being calcined, it is broken down into pieces varying from the size of a hen's egg to that of a walnut. With these the floor of a reverberatory furnace is covered, which generally takes about five hundred weight, and there it is frequently stirred with an iron rake until each piece becomes red hot throughout, this being sufficient to drive off the carbonic acid, which is usually effected in one hour. The loss by this process is about 34 to 36 per cent., and it incurs a further loss of 3 or 4 per cent. by picking after the calcination, the action of the fire rendering the presence of any extraneous mineral, or *deads*, as such matter is called, more apparent. By these processes a ton of calamine,

as received from the mine, is reduced to $12\frac{1}{2}$ or 12 cwt. before it is fit to be sent to the mill.

The chief disadvantages that would arise from the calamine not being sufficiently calcined, are the difficulty of grinding it, and the obtaining a less produce of brass from a given weight put into the crucibles, in consequence of part of that weight being carbonic acid. Some inconvenience would also result from the extrication of a large quantity of carbonic acid during the process; though this is the case to a considerable degree at present, from the decomposition of the oxide of zinc, by the charcoal which is mixed with it. Care and experience are necessary in conducting this process of calcination; for if the calamine be not properly calcined, the zinc will not be sufficiently volatile to rise through the materials in the crucible, so as to unite with the copper; and if it be over calcined, the brass resulting from it will be brittle. Another disadvantage also arises from its being exposed to too great a degree of heat, namely, its vitrification on the surface, especially when either siliceous earth or the silicate of zinc is present, which is not unfrequently the case; and the part which is vitrified cannot afterwards be reduced by the usual means.

When the calamine has been calcined, it is ground to a fine powder, and this is rendered more uniform by passing it through proper sieves; it is then removed to a building called the *buddle-house*, where it is washed in an apparatus of a singular construction, for the purpose of separating the sulphuret of lead and other extraneous matters which are frequently mixed with the calamine.

The zinc-ore having been thus prepared, it is mixed either with small pit-coal, or ground wood-charcoal, in the proportion of rather more than one bushel of carbon to one bushel of calamine. In the best manufactories, mineral or pit-coal is now entirely discarded, as it frequently contains minute veins of sulphuret of iron; and experience has proved, that when such coal is used, it either spoils the brass, or makes it of an inferior quality.

In order to charge the furnace, 60 pounds of the prepared calamine, with a proportional quantity of ground charcoal, are carefully mixed with 45 pounds of the granulated copper above mentioned, and then the whole is put into eight crucibles, this being the number that is usually taken to charge the bed of one of the furnaces. For making the finest and best alloy, a quantity of old scrap brass is generally added to the mixture in the crucibles, as this is found to render the metal more ductile, and consequently much fitter for making brass wire. When the crucibles thus charged have been placed at regular distances from each other on the floor of the furnace, the spaces between them are filled with pit-coal, which immediately becomes ignited

by the previous heat of the furnace. The orifice in the top of the oven is then partly closed by a circular piece of clay about 18 inches diameter, and the whole suffered to remain undisturbed for seven or eight hours; the workman having nothing to do with the operation during this period, but merely to keep open the draught-holes in the bed of the furnace, and to regulate the temperature by enlarging or contracting the orifice in the arch of the furnace from time to time, as the state of the process may require.

It will be proper, however, before entering upon the particular manipulations of this business, to describe the peculiar construction of the furnace and of the several apparatus connected with it.

In erecting a brass-work, the first thing is to sink a cellar beneath the intended building, for the reception of the furnaces, and of such a depth as will contain the whole height of the furnaces, and allow the opening in the roof to be exactly level with the surface of the floor of the chamber above them. One of these vaults generally contains four furnaces, each of which is built upon a cast-iron plate, called the furnace-bottom, three inches thick, and of a diameter somewhat larger than the area of the furnace. These plates are cast with eleven circular two-inch holes in each, for the purpose of allowing a sufficient access of atmospheric air, and these are distributed as in the annexed sketch, in which the circles represent the holes, the black spots

Figure 1.

A sketch of one of the furnaces.
Scale $\frac{1}{2}$ an inch to the foot.

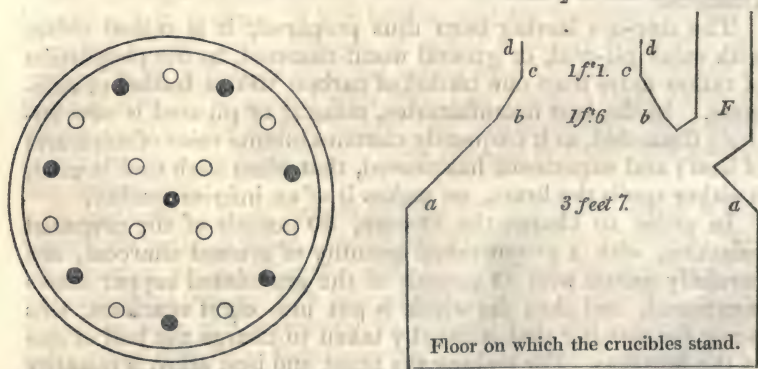


Figure 1. represents a perpendicular section of one of the furnaces. It is built perpendicular for 18 inches in height, or to *aa*. It is then contracted for 18 inches more, measured diagonally, to *bb*, at which place its diameter is 1 foot 6 inches. It is then contracted for 6 inches more, but at a different angle, to *cc*, where the diameter is only 1 foot 1 inch, on which a massy cast-iron ring, 3 inches deep and 3 inches thick, is placed at *dd* as a hoop to keep the brick-work together, and this forms the orifice of the furnace. *F* is a flue to the chimney described at page 202.

Figure 2.

A ground plan of the four furnaces to the scale of 1-8th of an inch to the foot.

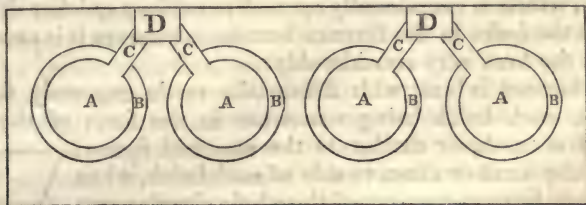
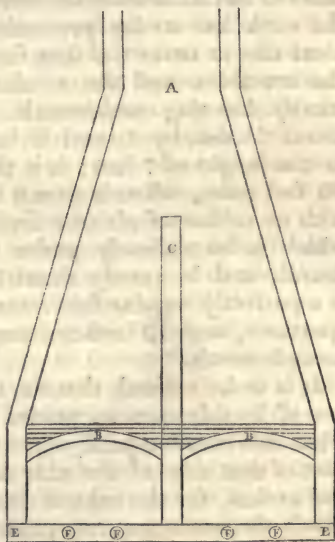


Figure 2. is a ground plan of the four furnaces under each dome. A A A A the interior of each furnace. B B B B the walls of the furnaces. C C C C the flues to the chimneys. D D the two chimneys which convey the smoke of the fires into the great dome or main chimney.

Figure 3.

Scale 1-16th of an inch to the foot.

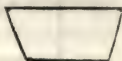
Figure 3. A, an elevation of the dome or great chimney which covers the four furnaces, and rises 42 feet perpendicularly above them. B B, two arches which support the front wall of the dome, and allow a passage to the hearth underneath the dome. C, a partition wall of brick-work called the *midfeather*, which facilitates the current and strengthens the building. E E, the hearth within the walls of the dome. F F F F, the entrances into the furnaces.



The plates are fixed upon brick-work of a sufficient height to admit of the removal of the ashes which fall through the orifices; and when one of these is properly fixed, the wall of the intended furnace is carried up in the usual manner upon it. The furnace is in a peculiar form, a perpendicular section of which is described in the accompanying plan (*Figure 1*), which is drawn to the scale of half an inch to the foot.

At F a flue of about 6 or 7 inches square commences, and is carried up perpendicularly along the inside wall of the great dome, to the height of 9 feet, where it discharges its contents. Each furnace has a similar flue, and each flue is furnished with a register, which is occasionally opened to excite a quicker draught through the holes in the furnace bottom, whenever it is necessary to raise the heat very considerably.

The furnace is built with fire-bricks made expressly for the purpose, each brick being somewhat in the form of the key-stone of an arch, or similar to the annexed figure; so that the small or concave side of each brick, when laid down, forms a segment of the whole circular area of the interior of the furnace.



When the four furnaces are completed, a quantity of loose earth is thrown in between them, and properly rammed, so as to form a floor, which is covered with a mixture of earth and carbonaceous matter. If it were paved with stones or bricks, the power of these in conducting caloric would render it impossible for the workmen to stand upon this floor; but as it is, there is but little inconvenience to those accustomed to it. When the work has so far proceeded, a chimney is erected of a sufficient size to cover the four furnaces and carry off the fumes of the crucibles, and the smoke from the fires, which are constantly burning underneath. This chimney, at its base, is about 24 feet by 8, and it is carried up of these dimensions to the height of 7 feet; it is then gradually narrowed for about 30 feet more, when it rises 6 feet perpendicularly, and finishes with an orifice of about 8 feet square. The carbonaceous floor which is immediately under this large chimney, is called the *hearth*, and is usually about 24 feet long by 8 feet wide. It is a perfectly regular floor, except that it has the four circular apertures, each 13 inches diameter, which proceed from the furnaces beneath.

It is to be noticed, that the two ends of the large chimney and one of its sides are supported by strong brick walls, while the other side remains partly open to the height of $6\frac{1}{2}$ feet, the upper part of that side of the chimney being upheld by brick pillars and arches, for the sake of leaving spaces or archways through which the workmen can pass from the adjoining workshop to the hearth. By this arrangement a room of any size may be attached to the hearth, and still the draught up the chimney preserved. In the works which I have seen, this room is about 24 feet square, which gives to the whole workshop an area of 24 feet by 32, and allows sufficient space for all the operations.

The crucibles in which the brass is made are round and of the usual form. Internally they are 8 inches in diameter at the

top, 13 inches deep, and $1\frac{1}{2}$ inch thick. As there is a great consumption of these crucibles, they are generally made in the brass-works. They are composed chiefly of a mixture of Stourbridge clay with another species found in the neighbourhood, together with some old broken glass-house pots coarsely ground, and a large portion of sand. The mixture of the ground pots with the other materials, enables the crucibles to bear sudden transitions from heat to cold, and *vice versa*, without cracking. Some of these vessels, which are worn out, present when broken, a beautiful amethystine colour throughout their texture, occasioned probably by the union of some particular proportion of carbon with the copper and zinc; as others, even after long wear, are not stained in this manner.

In commencing a new operation, the crucibles are filled one by one, as they are taken out of the furnace; and when nearly filled with the calamine, copper, scrap-brass and charcoal, the mixture is covered with a thick coat of ground charcoal only; and it may be remarked, that although the crucibles are red-hot, the workman smooths the surface of the charcoal and presses it down in the crucibles with the naked hand. When a crucible is thus filled, an attendant workman takes hold of it with a long pair of tongs, and, letting it down into the furnace, places it on the spot where it stood in the former operation. Having delivered this, he draws out another empty crucible to be filled in like manner, and this course is continued till the whole are charged, and commonly with such success that the same crucibles serve over and over again, sustaining the changes of temperature without accident for several operations.

The crucibles having been thus arranged, a man brings three bundles of gorse or furze, cut from the common, and thrusts them into the furnace; then large coals are thrown in till the oven is full. The gorse is intended to prevent the falling of the coals from breaking the crucibles, and also to favour the combustion, by keeping the coals hollow. When the furnace is thus charged, the mouth is partially covered by a thick piece of baked clay as before mentioned; the consequence of which is, that the draught to the chimney is kept up, which otherwise would have been checked or obstructed entirely by the large mass of fuel which is thrown in at once, and which remains some time before any considerable part of it can become ignited.

As soon as the combustion has fairly commenced, a curious spectacle presents itself, viz. that of furnaces burning beneath our feet, and four large bodies of flame rising through the floor on which we stand, and this so constructed that one may walk between these fires without danger, and without being even annoyed by the smoke. At this moment the workman is very attentive to the process, occasionally opening or closing the orifice on the top

of each furnace, so as to keep up with exactness the proper draught and no more. It is indeed necessary throughout the whole process to pay the greatest attention to the state of the fire, that there may be heat enough to decompose the oxide of zinc, and yet not enough to occasion that rapid reduction of it which would liberate the zinc-fumes faster than the copper could absorb them. The heat must be so regulated that it shall be sufficient to separate the zinc from its ore, and yet not great enough to melt the grains of copper, which would defeat the principal intention ; because the granulated copper becomes soft in a red heat, so that the zinc-fumes can penetrate it ; and this is all that is required until nearly the end of the operation, when the heat is raised so as to bring the whole into a state of perfect fusion, which is known to be the case by the apparent heat of the furnace, and the rapid extrication of the vapours of zinc.

It may here be observed, that in the old brass-works the calamine and charcoal were usually beaten into a hard mass at the bottom of the crucible, and then covered with a round plate of copper, which in a few hours became impregnated by the fumes of zinc from below. This, however, was a tedious mode of manufacture, as it was always necessary to re-melt the plates before an alloy of an homogeneous quality could be obtained. By the present management the copper absorbs the zinc gradually, and when it has acquired the proper quantity, the two metals melt together into one uniform mass.

In order to have the temperature of the ovens under constant control, care is taken to keep the holes in the floor of the furnace perpetually open, and this is effected by the workman now and then thrusting a long slender rod of iron through the arch of the furnace into them ; as he well knows that if he can procure a good draught from below, he will have no difficulty in regulating that draught by opening or shutting the register in the chimney, and enlarging or contracting the orifice on the top of the furnace. In first charging the furnace, he also takes care that the draught-holes are all covered with fuel ; for if it were otherwise, the air which passes through them could not be decomposed, but would considerably cool the furnace. However, as there is generally only one of these draught-holes between every two crucibles, a careful workman has little difficulty in keeping them sufficiently open, that is, free from slag or clinkers, and yet constantly covered with the fuel.

When the metal is ready for casting, a man opens the orifice in the arch of the furnace, and with a large pair of tongs draws out the middle crucible, and places it with its contents in the midst of a heap of hot ashes. He then withdraws another crucible in the same manner, when the foreman thrusts an iron rod into it, and stirs the melted brass a little, which has the effect of

cooling it in some measure, this being necessary, and of bringing to the surface any calcareous, carbonaceous, or foreign matter that may have adhered to the sides of the crucible. These being removed with an iron spatula from the surface of the melted metal, another man takes up the crucible with a pair of tongs and empties its contents into the first crucible. He then returns the empty one into the furnace and withdraws another, which is stirred, skimmed, and emptied as before. In this manner they proceed until the contents of the eight crucibles are collected together into one only.

A stranger cannot witness these operations without being surprised at the adroitness with which they are performed, and pleased with the unusual appearances that present themselves.

When the iron rod is thrust into the crucible by the workman, it occasions a combustion of the uncombined zinc, which burns with a white flame of peculiar brilliancy and beauty. The edge of this flame has sometimes a tinge of blueish green, which probably occasions the whole body of flame to exhibit a more chaste and delicate white than it otherwise would. Melted brass when exposed to the atmosphere *in a state of rest*, although at a high temperature, is protected from decomposition by a thin pellicle of oxide which forms on its surface; but when the melted mass is agitated by stirring it, there is a rapid and brilliant combustion of a portion of the zinc, which of course produces the white oxide of that metal, which is known to the workmen by the name of *calamine bloom*.

It may here be observed that the calamine is paid for according to the brass which is produced; the waste of zinc which is occasioned by this combustion is therefore the miner's loss, and not that of the manufacturer.

The whole of the metal having been collected into one crucible in the manner already described, the workman stirs it again with his iron rod, which produces another brilliant combustion. He then carefully skims the whole mass to remove whatever extraneous matter the stirring had brought to the surface, and wipes the edge of the crucible to remove any thing that may adhere to it. Every thing being thus prepared, another workman brings a pair of callipers of a peculiar construction, with an iron cover attached to them, so that when the instrument is opened to embrace the crucible, the cover slips over it to prevent any thing from falling in, and to preserve the heat of the metal while it is carried to the moulds on the other side of the laboratory. This is done by two men, who lift the crucible between them, and pour its whole contents into a mould formed of two blocks of granite, to be described hereafter. A plate of sheet brass is thus formed, which is usually $5\frac{1}{2}$ feet long, 15 or 16 inches wide, and half an inch thick, weighing about 108lbs.

Sixty pounds of calamine will produce about 22½lbs of zinc, which, with 45lbs of copper and 40lbs of scrap brass called *shruff*, produce a sheet of brass of the above weight. The whole process is usually finished in about seven or eight hours; I am informed, however, that when the brass-works were going at Holywell, they required from eighteen to twenty hours to complete the process. Formerly, indeed, the operation was never finished in any of the English brass-works in less than two days and nights, and from that to four or five days, according to the goodness of the calamine.

Frequently, however, a mineral called black jack or blende is used instead of calamine for making brass. This is found in abundance in many mining countries, and has long been in use at the Bristol brass-works; though, being a sulphuret and not a carbonate of zinc, it requires a long calcination in a reverberatory furnace to burn off the sulphur, before it is fit for forming an alloy with copper. On the other hand, the red oxide of zinc, which occurs in several parts of the United States of America, will, without any previous preparation, produce, when united with copper, brass of the best quality, possessing a very great degree of malleability and ductility¹.

The moulds which are employed in England for casting sheet brass are made of granite from Cornwall, though formerly we imported this stone from Holland, and afterwards from St. Maloes in France, not knowing that it might be procured at home. The great brass-works at Aix la Chapelle were supplied also from St. Maloes. The blocks employed in our brass-works are generally about 6 feet long, 3 feet wide, and from 7 to 9 inches thick, and usually weigh one ton each; but they require much preparation before they are fit for the purpose above mentioned, and in a large work many pairs of them are required to be in constant readiness. Care is also taken in the selection of the granite, for if it be of too close a grain it is apt to fly on the application of heat; whereas on the contrary, if the crystals of felspar are large, they are apt to fall out when the blocks have been used a short time, and the moulds, whatever may have been the expense in preparing them, are spoiled. When the granite is suitable for the purpose, a pair of moulds will sustain constant wear for eighteen months or two years.

To prepare the granite for use, each block is surrounded with a strong iron band, one inch thick and two inches wide, the narrow edge of the iron being placed against the edge of the stone. To these bands strong hooks are firmly affixed, and by means of these the blocks of stone can at any time be connected with a crane and moved to any part of the room as occasion requires.

¹ Bruce's *American Mineralogical Journal*, page 69.

The hooks are also useful for raising the upper block from the lower one to take out the sheet of brass that has been cast, and to dress the face of each stone for the next casting. In order to separate these massy stones from each other with the greater ease, the upper one is hung upon two strong iron pins which serve instead of hinges, so that whenever the hook of the crane is attached to the swivel in the upper stone, a few turns of the windlass will elevate that stone on its back edge, and allow the workman to dress the face of either as he sees occasion; but in fastening them together the longest stone is fixed below, and this is allowed to project a few inches at one end beyond the upper one, to form a kind of bed, on which the brass is poured from the crucible, and from whence it readily runs into the mould. When these stones are thus fixed on their pivots, they open like the leaves of a book without being entirely separated from each other; and are put together again by means of the crane and pulley with the greatest ease; though it will be obvious that they are never allowed to come into actual contact. There must be room for the metal which is to form the sheet of brass to run between them; and to effect this, the two blocks of granite are kept at a proper distance from each other by ribs of iron, which vary in thickness according to the thickness of the plate of brass intended to be cast. These are not fastened in the first instance, but are merely laid loose upon the undermost block, and the screwing of the two blocks together fastens them. They are called *shin irons*.

It should have been observed that before these blocks of Cornish stone are fit for use they are in some measure dressed by a mason, and then the inner surface of each is plastered over with a very thin coat of common loam, for the purpose of giving it a smooth face. Any small fissures that afterwards appear in the loam, from the heat of the melted brass cast upon it, are filled up by smearing the surface over with a little cow-dung, which is generally done each time; and by this trifling expedient the mould is rendered fit for receiving the next casting. Formerly the moulds were covered with a coating of ground coal and tallow, but the present method is the more efficacious.

When the mason has prepared a pair of new blocks of granite, and the smith has bound them with iron and attached the apparatus for screwing them together, they are fastened by a kind of swivel to a strong beam of wood, for the purpose of altering their horizontal position, whenever the brass is required to be poured into them.

Things being so far arranged, the two slabs of granite are screwed firmly together, with the ribs of iron already mentioned between them. A perfect stone mould is thus formed, open at one end for the sake of pouring in the fluid metal.

The beam of wood to which the blocks of stone are attached,

is so contrived that when the crane is hooked to one end of the mould, it can thereby be raised, while the other end sinks into an excavation in the floor of about two feet deep, which gives the stones an angle of 30 or 35 degrees; and this has been found to be the most convenient declivity for pouring in the metal.

It may be mentioned that the moulds for casting sheet brass were very different formerly, as appears from plate xxxv. in the *Fleta Minor* by Sir John Pettus.

When the plate of brass has been cast in the way already described, a minute or two is only allowed to intervene before the workman loosens the screws to take out the new plate of metal, and again dresses the interior of the mould with the usual coating, to prepare it for the next casting. He then covers the slabs of granite with thick flannel blankets doubled together, and lays four or five one over the other, in order to preserve the mould of a proper temperature for receiving the castings of the next day. The coating of loam first spoken of requires to be renewed after every ten or twelve castings; the old coating being previously removed by rubbing the face of one block against the other. To effect this purpose a quantity of brass shot of a size less than that of pepper-corns is introduced between the two blocks, which causes the upper stone to move with comparative ease over the face of the lower one, and by this abrasion to disengage the whole of the old indurated coating.

These are the methods by which the manufacture of brass-plates is usually conducted. When the metallic alloy is of an ordinary quality it is generally not cast into plates, but into ingots of about 8 inches long, 2 broad, and $1\frac{1}{4}$ inch thick. These are sold to the brass founders for the purpose of small castings, and for making the alloys of tombac, pinchbeck, &c. These ingots are usually formed in moulds made with cast-iron.

The plates of which I have described the manufacture so much in detail, are generally taken from the brass-works to the mills: there some are rolled whole into large sheets of very thin brass called *latten*; others are cut into long slips, and these are again rolled to about the thinness of one-twentieth of an inch; they are then slit into *strings* as they are called, and in that state are taken to the wire mill to be drawn into wire, for making pins or for any other purpose to which brass wire is applicable.

This, however, is an operation of some nicety, because the act of drawing the brass through steel plates renders it so brittle that it is necessary to anneal it afresh after each drawing; and for small wire this is frequently repeated, as the metal is successively drawn through holes of different degrees of fineness before it is sufficiently reduced. The annealing is performed by heating the wire to a little below a red-heat, and then suffering it to cool

gradually, which renders it as soft and as pliable as at first. It is not plunged into cold water like *copper* wire, though by so doing it would not be hardened like iron and steel wire when so treated. Copper wire when annealed is plunged whilst red-hot into cold water; but this is more for the sake of throwing off the oxide which it has contracted by being heated in contact with atmospheric air. It may here be remarked as a curious fact, that to anneal *iron* wire a contrary practice must be adopted; the iron wire must be heated red and suffered to cool gradually, for if it were treated like copper wire it would be rendered perfectly brittle. In annealing brass wire care must be taken not to heat it up to what is called a cherry red, which is easily done in wire of great fineness, because the zinc in that case would be separated and copper reproduced.

The largest consumption of brass wire is in the manufacture of pins, and for this purpose it is indispensable; the reasons will appear when we come to consider the properties of brass as distinct from those of copper. There is likewise a considerable consumption of brass in the manufacture of what are called *brasses* or *bushes*, in which the spindles of machinery usually run; also for carriage harness, the furniture of houses, culinary utensils, and other domestic purposes.

Brass was made with the utmost secrecy in Germany for several hundred years; and some individuals raised themselves to great opulence by its manufacture. The first work for the manufacture of brass that was erected in this kingdom, was begun at Esher, in Surry, by one Daniel Demetrius a German, in the year 1649, and the whole of the metal was then made with *rose* copper imported from Sweden¹; some English merchants however, who had been accustomed to export our calamine to the continent and derived profit from the importation of foreign brass, contrived to involve Demetrius in a suit at law, which ruined him and obliged him to give up the concern. Other works were erected soon afterwards in Southwark and at Woolwich; and Lord Byron had a large establishment in Nottinghamshire for making brass, and these together with the London works employed 8000 men daily. But Sir John Pettus, who wrote in 1670, tells us² that in his time the works had decayed and "the art of making brass was almost gone, as well as the artists, from the kingdom."

The first mill in Great Britain for drawing brass wire, was erected by a Dutchman near Richmond in the year 1663.

The places in this country where brass is now manufactured

¹ Houghton's *Collections*, vol. ii. page 188.

² *Fodinae Regales*, page 33.

to any extent are at Framilode in Gloucestershire, at Bristol, at Birmingham, and at the towns of Cheadle and Stone in Staffordshire. The works at Bristol are the most extensive in the kingdom, and have been the longest established. The manufacture of brass was indeed confined to the city of Bristol for many years, and as other works became established the workmen were generally procured from thence. There were formerly *two* great works near that city, but one of these has been long shut up. The house of Harford and Co. has been the longest established, and is now in full work. There are no less than four works in Birmingham where brass is made for sale; besides which several of the consumers themselves in that town make a portion of what they use, though this is chiefly of an inferior sort.

The most useful alloy of copper and zinc, as far as I have been able to ascertain, is that which is composed of two parts by weight of copper and one of zinc; and this is not far from one proportional of each metal, reckoning the equivalent number for copper to be 64 and that of zinc 35; but the proportions of the two metals are frequently varied according to the purposes for which the alloy is required. Dutch-brass, which is imported for the use of the manufacturers of watch movements, is a compound of two proportionals of copper $64 \times 2 = 128$ + one of zinc $35 = 163$. Prince's metal is composed of one proportional of copper $64 + 2$ of zinc $35 \times 2 = 70$, forming a metallic alloy $= 134$.

According to Weigleb, the alloy called *Manheim-gold* is composed of

$$\begin{array}{r} 3 \text{ proportionals of copper } 64 \times 3 = 192 \\ 1 \text{ proportional of zinc } \dots \dots = 35 \\ \hline 227 \end{array}$$

Pinchbeck is said to contain a less proportion of zinc than any of the alloys of copper usually made in this country, but I am not acquainted with the proportions.

French brass is formed occasionally with different proportions of the two metals; but that which is manufactured for common consumption is a compound of

$$\begin{array}{r} 4 \text{ proportionals of copper } 64 \times 4 = 256 \\ 1 \text{ proportional of zinc } \dots \dots = 35 \\ \hline 291 \end{array}$$

It is observable that this alloy contains very little more than 12 per cent. of zinc, whereas our brass holds usually more than 35 per cent. of that metal. The best English tombac however contains still less of zinc; but then the colour of the copper is lowered by the addition of tin. Tombac is usually made with 16 parts of copper by weight, with one of tin and one of zinc. Its

real proportions, considering the loss which arises from the volatile nature of the oxide of zinc, are probably,

15 proportionals of copper	$64 \times 15 = 960$
1 proportional of tin	59
1 proportional of zinc	35

1054

Brass is peculiarly useful to many of our artists and workers in metals, because it may be easily combined by fusion with additional portions either of zinc or copper; thus if brass be combined with a large proportion of zinc, it forms an alloy known in Birmingham by the name of white metal, which is used in large quantities for the manufacture of what are called white-metal-buttons; on the contrary, pinchbeck, tombac, Dutch-gold, Mannheim-gold, semilor and Prince's metal, are made by fusing brass with an additional quantity of copper. The alloys last mentioned have all a rich yellow colour and will bear a high polish.

The peculiar properties of brass may be thus enumerated:—Brass is harder than copper, but not sufficiently hard to strike fire like steel. It melts with less heat than copper, which makes it more convenient for small castings. It does not rust or oxidize so soon as copper. It is also more suitable for turning in the lathe, as it is worked with greater ease and cuts smoother, and it will also bear a higher polish. It is ductile only when cold, but this ductility greatly exceeds that of copper; consequently it can be drawn into wire of superior fineness. It is remarkable that copper should acquire such great ductility by its union with zinc, as zinc is of itself a very brittle metal. Brass is more combustible than copper, which is proved by the circumstance of a brass wire burning in chlorine gas, which is not the case with copper. Brass is more tenacious than copper, and therefore fitter for being fashioned by hammering. On this account it is commonly used for very fine work, such as mathematical, philosophical, and astronomical instruments. It expands by heat more than copper, but in a less degree than zinc. The degrees of its expansion at different temperatures were determined by Mr. Smeaton nearly seventy years ago. Its colour is paler than that of copper, which gives it a great resemblance to gold. It is more sonorous than copper, which occasions its employment very generally for musical instruments; and from the experiments of Lewis, as detailed in the *Commercium Technicum*, it appears that a very useful alloy of platinum and brass may be formed, which bears a very fine polish and does not tarnish by exposure to the atmosphere. Mr. Leslie has discovered that of all the metals or metallic alloys *brass* possesses the property of reflecting light and heat in the highest degree. This circumstance will probably occasion its employment for purposes to which it has not hitherto been applied.

ESSAY VII.

ON SULPHURIC ACID.

WHEN sulphur mixed with a certain portion of nitre is burnt over water, in a closed vessel containing atmospheric air, a peculiar acid is formed during the combustion, which is known to chemists by the name of SULPHURIC ACID.

This acid is formed in many of the operations of nature¹, but we have no reason to believe that the ancients knew this, although they were well acquainted with its base, sulphur², which they sometimes employed with other combustible substances in religious oblations. So early as in the first century sulphur was employed in bleaching woollen cloth, and for other purposes, as may be seen in the Essay on Bleaching.

Vitriol, or sulphate of iron, is mentioned by Pliny in his Natural History; but it does not appear that he knew any thing of its chemical composition.

Aulus Gellius relates that Archelaus, one of the generals of Mithridates, washed over a wooden tower with a solution of alum, and by this project rendered it so much proof against fire, that all the attempts of Sylla to set it in flames proved abortive. There is, however, no question but that this was *sulphate of iron* which was applied, for it has been proved that the ancients gave this salt the name of alum.

The first mention of sulphuric acid occurs in the writings of Basil Valentine, a celebrated chemist of Erfurt. In his time, however, the quantity produced must have been small, and its consumption very circumscribed. It was also known to Paracelsus, the Swiss alchemist, who died so early as the year 1541; and it is evidently referred to likewise in a work entitled *De Re Metallica*, which was published by George Agricola, a German physician, in the year 1542; but I know of no proper characteristic description of this acid by any of the writers of that period. The first person who gave any thing like a correct account of sulphuric acid was Gerard Dornæus, in a work which he published in the year 1570; and again in another edition of the same work, which he republished at Frankfort in the year 1581³.

¹ Disengaged sulphuric acid has occasionally been found native in some parts of Italy; *Journal de Phys.* tom. vii. page 395.

² Pliny, lib. xxxv. cap. 15.

When sulphuric acid was first prepared by art, it was distilled from dried sulphate of iron, the common *green-vitriol* of commerce. Hence, when the component parts neither of the salt nor of the acid were known, it was very naturally called *oil* of vitriol: or it might have acquired the name of *oil* of vitriol from the circumstances of its resemblance to oil in adhering to the sides of a vessel containing it, and in its occasioning little noise when poured from one vessel to another.

This name should now be expunged, as it tends to give false ideas of the nature of the acid, and may mislead and bewilder a young chemist. Oil does not mix with water, but sulphuric acid does in all proportions; oil is composed of hydrogen and carbon; but neither of these substances enters into the composition of sulphuric acid, which has been demonstrated by analysis as well as synthesis to be formed only of sulphur, oxygen, and water.

Sulphate of iron is prepared from martial pyrites, which is a native sulphuret of iron. It is found in abundance on the island of Sheppy and elsewhere. By exposing this to the air in large beds, oxygen is absorbed, the sulphur becomes sulphuric acid, and the newly formed salt is separated by washing.

All the sulphuric acid which is prepared in Saxony, and in many other parts of Germany, is still procured from sulphate of iron. In the *Journal de Physique* there is a very particular account, by Mr. Fragosio, of the distillation of this acid from copperas, as it is now practised at Bleyl, a village in Bohemia⁴. To conduct the operation in the best manner, seven or eight days will be required, and during two-thirds of this time the fire must be kept at the highest pitch. Bernhardt, who was well acquainted with this process, tells us that he procured only 64 pounds of sulphuric acid from six hundred weight of sulphate of iron. Directions for conducting the operation have also been given by Glauber; but according to him, a much purer sulphuric acid may be obtained from sulphate of zinc, and with less labour⁵.

At one time the English makers of sulphuric acid distilled the green vitriol in earthen vessels called long-necks, placed within a reverberatory furnace with a glass receiver luted to each retort. It was usual to put fifty or more of these into one furnace⁶.

³ This work is entitled "*Congeries Paracelsicæ Chemiæ de Transmutationibus Metallorum, ex omnibus quæ de his ab ipso scripta reperire licuit hactenus; access. Genealogia Mineralium atque Metallorum omnium.*" 8vo. Francf. Wechel. 1581.

⁴ An abridgement of this account may be seen in the thirteenth volume of the *Repertory of Arts*, page 269.

⁵ The Works of John Rudolph Glauber, folio, London, 1689, page 17.

⁶ Dr. Lewis's Edition of *Neumann*, vol. i. page 277.

The makers of sulphuric acid having found great inconvenience in procuring it from sulphate of iron, on account of the length of time which was necessary for the operation, the small quantity of acid that was procured by this means, and the intense heat required for its distillation, which always destroyed the stills with great rapidity, and entailed upon them a perpetual and enormous expense, had at length recourse to the base itself, to the sulphur, which, in conjunction with nitre, was burnt in very large globes of glass, and the product was concentrated by boiling it in retorts or other glass vessels, until the fluid was of a sufficient strength for sale.

It may be proper, however, before we proceed with the account of the manufacture of sulphuric acid, to say a word or two respecting the sulphur.

Sulphur, or brimstone as it has usually been called, is a simple combustible substance, quite undecomposable, at least by any of our present methods of analysis, and it differs in its nature and properties from all other known bodies. It is chiefly procured in the neighbourhood of volcanoes, and also from some of the native sulphurets; but what is used in this country is usually imported from Sicily. Its chief consumption is in the manufacture of sulphuric acid; though it should be recollected, that if sulphur be burnt without any admixture, *sulphurous* and not sulphuric acid will be formed.

Sulphur burns very differently in different circumstances; Stahl found that an ounce of sulphur, burnt with a wick, may be made to yield a constant flame for six hours; and that when the wick was very small, only 15 or 16 grains were consumed in an hour. When sulphur is heated to about 190° , combustion begins, and a pale blueish flame is emitted with the production of a very small degree of heat. The heat thus generated is so inconsiderable that Baumé contrived to burn off the whole of the sulphur from a quantity of gunpowder without exploding the powder¹.

I have seen no account of the preparation of sulphur in any of the modern systems of chemistry. A few particulars relating to the process which I shall insert, believing they will be acceptable to the reader, appeared in the *Phil. Trans.* 1665, page 45.

“The mineral out of which brimstone is extracted at Liege is not much unlike lead-ore, having also oft-times much lead mingled with it, which is separated from it by picking. To make brimstone, they break the ore into small pieces, which they put into crucibles made of earth, five feet long, square and pyramid-

¹ Macquer's *Dictionary*, article *Sulphur*.

wise. The entry is near a foot square. These crucibles are laid sloping, eight undermost, and seven above them, as it were betwixt them, that the fire may come at them all, each having its particular furnace or oven. The brimstone, being dissolved by the violence of the heat, drops out at the small end of the crucible, and falls into a leaden trough or receiver common to all the said crucibles, through which there runs a continual rivulet of cold water, conveyed thither by pipes for the cooling of the dissolved sulphur, which is ordinarily four hours in melting." From the ashes left in the crucibles they afterwards make crystallized sulphate of iron.

Sulphur is a hard and brittle substance of a yellow colour, which very much varies in its intensity; it has neither taste nor smell unless it be heated. When melted in a large mass, it crystallizes on cooling. Such crystals as are transparent are in a high degree doubly refractive; and its specific gravity, when tolerably pure, is about 1.990. It has the property of becoming negatively electrical by heat and by friction. It liquefies at the heat of 225° , and this liquid becomes thicker and thicker as the heat is increased; and when it has acquired the heat of 560° or 600° , it begins to sublime, and the article known in commerce by the name of *flowers of sulphur* is produced. Roll sulphur is generally procured from British sulphuret of copper: this is at first separated from the mineral by sublimation, and then the sublimed sulphur is remelted and purified before it be cast into sticks for sale. When sulphur is pure, it will evaporate entirely, and leave no residuum. Its purity may also be judged of by dissolving a portion in boiling oil of turpentine; for if pure, every particle will be dissolved by the action of that menstruum. The equivalent number for sulphur is 16.

It is generally understood that the sulphur which is imported varies very much in its quality; and this is confirmed by the different accounts we have of its specific gravity, which varies from 1.800 to 2.3440.

The process of forming sulphuric acid by the combustion of sulphur is so very different from the original method of procuring it by the simple distillation of sulphate of iron, and has occasioned such important changes in a variety of the manufactures of the country, that I have considered it to be right to take some pains to trace the progress of the new method; especially as it will in a few years be difficult to acquire any correct information on the subject; and as I had formerly some connexion with the family of one of the principal original manufacturers, I obtained the possession of some facts which I am desirous of communicating to the public. Moreover, the gratification which arises from

being the means of recording the origin of a manufactory of so much importance as the process for producing this acid in an economical way, will, I trust, be my excuse for allowing the following detail to occupy so much room in this Essay.

The method of forming sulphuric acid by the combustion of sulphur was first adopted in this country by Dr. Ward, the vender of many celebrated nostrums which bear his name. It has generally been said that Dr. Ward was the author of this important discovery; but Fourcroy attributes it to two French chemists, Lefevre and Lemery. The works of the latter I have consulted, and in an edition printed more than a century ago, I find an express process for producing sulphuric acid by the combustion of sulphur and nitre; though it is probable that before Dr. Ward's time the quantity made in this way was very inconsiderable; for Lemery tells us that he prefers the acid made without nitre¹. An exclusive right to this mode of making sulphuric acid in Great Britain was, however, granted to the Doctor by patent; and, by way of distinction, the article which he prepared was called "Oil of vitriol made by the bell," and was sold from 18*d.* to 2*s.* 6*d.* per pound.

The glass vessels which were employed for this process were made with wide necks, and as large as they could be blown with safety, and capable of holding forty or fifty gallons. These were placed in two rows on a bed of sand, and at a sufficient distance from each other to be conveniently approached. A few pounds of water being poured into each glass, a stone-ware pot was introduced into the neck, and on this was placed an iron ladle previously made red-hot. Into this last, by means of another ladle of tin-ware, a mixture of sulphur and nitre was put, and then the aperture of the glass vessel was immediately closed with a stopper of wood. The heat of the iron ladle set the sulphur and nitre on fire; and when the combustion was finished, the iron ladle was taken out, and the vapours suffered to condense.

The same operation was successively conducted in each of the glass vessels composing the two rows; so that the workman, after passing through the whole range, arrived at the first vessel at the time when the vapours were totally condensed, and the vessel consequently in a state to receive a new portion of the matter for burning.

The British manufacture of this acid was thus monopolized by Dr. Ward for a considerable time: but when the term of his patent expired, several other persons became engaged in the

¹ Fourcroy's *System of Chemical Knowledge*, London, 1804, vol. ii. p. 83. Lemery's *Chemistry*, London, 1698, page 448.

business, and conducted it after an improved method. Mr. Dossie has given a very particular description of his method, and of the glass globes and other apparatus which were employed in his time for the purpose; from the perusal of which the nature of the manufacture will be thoroughly understood². At length, however, chambers of lead were employed for the combustion of the sulphur and nitre, which were so contrived that the floor of each might be constantly covered with a sheet of water, capable of absorbing the sulphuric acid gas at the time of its formation.

The introduction of the leaden apparatus is a memorable event in the history of the progress of this manufacture, as it has laid the foundation of its present magnitude, and in a short time reduced the price to about one twelfth part of its former rate.

The credit of this very important improvement belongs to the late Dr. Roebuck, an eminent physician of Birmingham, who, in conjunction with his partner, the late Mr. Samuel Garbett, erected the first leaden chamber for this purpose, at Birmingham, about the year 1746.

Owing to the interior situation of these works, and the great expense and risk of land carriage, there being at that time no conveyance by canals, the consumption was almost entirely confined to that town and neighbourhood. A considerable portion of the acid was employed in the distillation of nitrous acid, which is in great demand there for the use of the various manufactories. Much of it was also used as a solvent for copper, for the double purpose of making Roman-vitriol, and of recovering the gold and silver from waste gilt and plated metal.

These manufacturers, however, were not long satisfied with this confined consumption: in order therefore to create a more extensive demand, and likewise with a view to the introduction of it for the purpose of bleaching in the linen manufactories of Scotland and Ireland, in the year 1749 they established works at Prestonpans on the eastern coast of Scotland on a very extensive scale.

That nothing might be neglected which was likely to promote this object, Dr. Home, then professor of chemistry in the university of Edinburgh, entered upon a course of experiments to ascertain the powerful effects of sulphuric acid, when properly employed, in whitening linen cloth without prejudice to the fabric. These experiments were afterwards published, together with directions as to the mode in which the new agent ought to be employed. This, by degrees, had the desired effect, and

² Dossie's *Elaboratory laid open*, Oct. 1758, Introduction, page 44.

finally exploded the use of sour milk, which till then was the only acidulous article that had ever been used in bleaching.

In reverting to the manufacture of sulphuric acid, it ought to be noticed that for several years Messieurs Roebuck and Garbett carried on their works in England and Scotland with great success and without any opposition. They not only supplied the demands of Great Britain and Ireland, but exported very large quantities of sulphuric acid to the continent of Europe.

About the year 1756, one of their workmen at Birmingham absconded from their service; and being a native of Bridgenorth, went thither, and had the art to induce a Mr. Rhodes, an eminent seed-crusher, and proprietor of large oil-mills in that town, to embark in the business.

A small work was accordingly set up at Bridgenorth, on the banks of the Severn, and there the manufacture was carried on for many years. This man did not, however, continue long with Mr. Rhodes; but engaged himself to Mr. Skey of Bewdley, who had just begun a manufactory of sulphuric acid on a scale much larger than that at Bridgenorth.

This establishment was also on the banks of the Severn, at a place called Dowles, near the town of Bewdley, in the county of Worcester, and was the third English work for manufacturing this valuable commodity by the combustion of sulphur in leaden chambers.

At first these chambers were only six feet square; but Mr. Skey erected his ten feet square, and in vessels of that size he continued the manufacture for many years.

These chambers were erected under the direction of a man who had formerly worked at Prestonpans, and who, having been discharged from thence, was travelling through the country with his family in search of employment.

Mr. Skey, who was a man of great enterprise, having by accident seen this individual and heard his account of the nature of the business, at once determined that he would engage in it, and manufacture the article on as large a scale as its demand should require.

Such was the origin of the extensive manufactory at Bewdley; and as the materials at that time were cheap, and the acid was sold dear, this establishment was the means of raising its founder to a state of great opulence. At his decease, the whole of the chemical works were carried on by his son the late Samuel Skey, Esq., and since his death they have been continued, and are still in full work, for the benefit of his children.

Considering the nature and importance of Dr. Roebuck's improvement, it is a remarkable circumstance that similar esta-

blishments were not sooner formed in various parts of the kingdom; and that twenty-five years should have elapsed before any spirited individual in the metropolis, or in its vicinity, had availed himself of the advantages of the invention.

According to the best information which I have been enabled to obtain, Messieurs Kingscote and Walker, druggists of London, were the first persons south of Birmingham who attempted to make sulphuric acid in vessels of lead. Their manufactory was established in the year 1772, at Battersea, four miles from London, and on the 24th day of December 1771 the first barge-load of lead was navigated on the Thames up to Battersea for the construction of the chambers.

This establishment consisted of seventy-one circular leaden vessels, each six feet in diameter and six feet in height, constructed in the following manner:—A sheet of lead was folded round a wooden cylinder prepared for the purpose, and upon this immense maundrel the vessels were formed into shape, and then the edges of the sheets were lapped together and soldered. Each vessel was afterwards reared on one end upon a bottom of lead, and when thus fixed, it was covered with a dome of lead firmly soldered upon it.

These receptacles had each one aperture, which, during the time of the combustion of the sulphur, was closed by a door of mahogany nicely adapted to it: besides which, each vessel had an outer door of the same species of wood to be shut before the former, in order to close the opening the more effectually. These rooms stood in five separate rows, independently of each other, and all were inclosed in one large brick building, to preserve them from the effects of the sun and wind.

Besides the apparatus which I have described, these manufacturers erected also several square houses of lead, which were perfect cubes of twelve feet each; and these, together with the former, were regularly employed for many years. I have been the more particular in describing this work, as I conceive it to have been the most curious and expensive establishment that was ever formed in these kingdoms for a similar purpose.

Several unfortunate circumstances, not worth relating at this period, conspired to render this manufactory unproductive of profit; in consequence of which it was at length broken up, the vessels were taken down, and every thing was sold by auction under the description of old materials.

Soon after the destruction of this manufactory, Mr. Walker, a nephew of one of the late partners at Battersea, connected himself with two other gentlemen, and they, under the firm of Baker, Walker, and Singleton, some time about the year 1783 established a sulphuric acid manufactory of very considerable extent at Pitsworth-Moor near Eccles in the county of Lancaster. This

manufactory, which was the first establishment of the kind in that county, consisted of four vessels each twelve feet square, and four others, each of which was forty-five feet long and ten feet wide.

Not long after the formation of this manufactory, another work was established at Leeds; and by degrees they have spread into most parts of England and Scotland, as well as Ireland.

When the formation of sulphuric acid by combustion in leaden chambers was completely established by Dr. Roebuck, little or no improvement was made in the manufacture for many years. However, in the year 1788, a memorable era in the history of the trade of this country, when the new method of bleaching by chlorine was introduced, the sale of sulphuric acid was much increased, especially in some particular districts. From this time the demand became enormous, and almost unlimited in extent; so that, from this single and unexpected circumstance, the manufacturers of this acid found it necessary to erect chambers of much larger extent for the combustion of the sulphur; and these have been enlarged again and again by the great makers, so that now a common rate manufactory for sulphuric acid is really an establishment of serious concern in respect to capital and magnitude.

The size of the leaden chambers in modern use is from 20 feet long and 12 wide to 40 or 60 feet long and 16 or 18 feet wide. One manufacturer, however, in Lancashire, has several leaden chambers of the enormous dimensions of 120 by 40 feet, and 20 feet high, consequently forming a space of 96,000 cubic feet each.

The process, however, whatever may be the size of the chambers, is generally conducted in the following manner:—A quantity of common brimstone, coarsely ground, is carefully mixed with crude saltpetre in the proportion of seven or eight pounds of the former to one pound of the latter; and this mixture is afterwards divided into separate charges, containing quantities proportioned to the size of the chamber in which they are intended to be burnt.

The best method for apportioning the mixture of sulphur and nitre to the size of the house, appears to me to be this: to allow one pound for every 300 cubical feet of atmospheric air contained within the chamber; that is, if a house be an oblong square of 40 feet by 15 feet, and 15 feet high, the contents in cubic feet will be 9,000, and such a chamber will take 30 pounds of the mixture at each charge.

The mixture of sulphur and nitre is usually spread upon several plates either of iron or of lead; and these are afterwards placed upon stands of lead within the chamber, at some distance from each other, and a foot or two above the surface of the water.

Things being thus arranged, the sulphur is lighted by means of a hot iron, and the doors are then closed.

If well mixed, the brimstone and nitre will soon be in rapid combustion, which will continue for 30 or 40 minutes, during which time the chamber will become entirely filled with gas.

Three hours, calculating from the time of lighting, are generally allowed for the condensation of this gas; and then it is customary to throw open the doors for a quarter of an hour or half an hour, for the free admission of atmospheric air and the expulsion of all the incondensable gas, in order that the house may be thoroughly sweetened, as it is called, for the next burning.

During this interval the plates are again charged, and preparation is made for a fresh combustion, which is thus repeated every four hours, day and night, without intermission, until the water at the bottom of the chamber is thought to be sufficiently acidified, which is generally when it has attained the specific gravity of 1.350. It is then drawn off, by means of a syphon, into a reservoir of lead conveniently placed for its reception, and the floor of the chamber replenished with water for another operation.

Whatever number of leaden chambers a manufactory may consist of, it is customary to work them all in this way, day and night, without interruption: for, as it requires a large sum in the first instance to form a sulphuric acid establishment, the operation being tedious, the return slow, and the product very small compared with the capital, the interest of money must be a heavy charge on the trade; and this is a constant spur to the manufacturer, making him anxious to get as large a produce as possible from each chamber.

When the acid has been drawn from the house, it is pumped from the reservoir into a large leaden boiler, which is usually an oblong square, and there evaporated down till it has attained the specific gravity of 1.700 or thereabouts.

Another reservoir is placed contiguous to the boiler, into which the concentrated acid is syphoned, where it is preserved, closely covered from the action of the atmosphere, until it is convenient to remove it to the rectifying house. There it is boiled in retorts of glass, until the remainder of the sulphurous and nitrous gas is driven off, and the acid has acquired the usual concentration for sale.

To explain why these different operations are necessary for procuring sulphuric acid in its highest state of concentration, it may be remarked, that whenever the acid in the leaden chambers has acquired a certain specific gravity, it will refuse to absorb the gas with the same avidity as at first; therefore, in order to conduct the process economically, the acid liquor must

at that time be removed, and water poured in to supply its place.

It is equally necessary, when in the leaden boiler, to draw it off before it becomes too much concentrated; because the boiling point of sulphuric acid always increases with the increase of its specific gravity; and its boiling point is so very near to that at which lead melts¹, that there would be great danger of the metal giving way, were an attempt made to concentrate the acid beyond a certain point in such utensils; to say nothing of the loss of that portion of acid which would be decomposed by the metal, and of the impurity which the remaining acid would acquire from the large quantity of lead that would then be dissolved.

From some late experiments which I have made on the fusibility of various compounds of lead and tin, I have been convinced that in the fabrication of leaden boilers the utmost attention ought to be paid to the *purity* of the metal, and care taken that no lead be used but such as is free from every alloy.

Having occasion a few years ago to purchase several tons of sheet-lead for the construction of an oil-of-vitriol chamber and other chemical apparatus, I accidentally discovered that there is often a great deal of sheet-lead in the market which has been manufactured from *old* lead, which usually contains some solder and other impurities. In the construction of steam boilers for the concentration of sulphuric acid, such lead ought to be carefully avoided; for a small portion of tin or plumber's solder, which is usually found in old lead, will when mixed with pure pig-lead reduce the melting point of the whole of the metal very considerably.

Having thus given but a brief account of the nature of this manufacture, it will be necessary to add a few words upon the properties of the acid which is the subject of this Essay.

I have already noticed that sulphuric acid is a compound of sulphur, oxygen, and water; but it must be observed, that sulphur is capable of forming with oxygen three distinct compounds, containing different proportions of oxygen, and possessing very different properties. Thus, if sulphur be burnt in oxygen gas over water, the water will absorb the sulphurous gas which proceeds from the combustion, and be converted to *sulphurous* acid; but if a certain proportion of nitrate of potash be mixed with the sulphur before it be ignited, the product of the combustion will be *sulphuric* acid.

Hypo-sulphurous acid, which exists only in combination with

¹ Lead melts at 612° of Fahrenheit; and Mr. Dalton states that the concentrated sulphuric acid of commerce of the specific gravity of 1.848 boils at 590°; but that if the specific gravity amount to 1.849, it will require a heat of 650° to bring it to the state of ebullition.

salifiable bases, and may be obtained by digesting the solution of a sulphite with sulphur, is composed of one proportional of sulphur=16, and 1 of oxygen=8=24 its equivalent number.

Sulphurous acid gas is composed of 1 proportional of sulphur=16, and 2 of oxygen=16; so that its equivalent number must be represented by 32.

Sulphuric acid is composed of 1 proportional of sulphur=16, and 3 of oxygen=24; so that the number representing *dry sulphuric acid*, or sulphuric acid in the state in which it is found in the native sulphuric salts, and in several artificial compounds, will be 40.

The strongest *liquid sulphuric acid* is composed of 1 proportional of sulphur=16; 3 of oxygen=24; and 1 of water=9, making its equivalent 49.

It is remarkable, that when sulphur is burnt in dry oxygen gas, the sulphur combines with the gas without increasing its volume. One hundred cubic inches of oxygen weigh 33.75 grains, and this volume of oxygen is capable of combining with 33.75 grains of sulphur; from whence it follows, that 100 cubic inches of sulphurous acid gas must weigh 67.5 grains, and this by experiment is found to agree exactly with the theory. The composition of sulphurous and sulphuric acids is therefore put beyond all doubt.

It was usually imagined that the formation of sulphuric acid is brought about by the union of the oxygen of the nitre with the sulphurous acid; but it was soon found by calculation that the nitre usually burnt with the sulphur is not adequate to the supply of one-thirtieth of the oxygen that is required for the conversion of sulphurous to sulphuric acid. The theory of its formation, which is borne out by experiment, is now considered to be this:—The two acid gases, the sulphurous and the nitrous, which enter the chamber together, have the property of combining and forming minute crystals on the sides of the chamber, which fall off and drop into the water. Here a decomposition immediately ensues, the sulphurous robs the nitrous of one portion of its oxygen, and becomes sulphuric acid, leaving the latter deutoxide of nitrogen; but this gas, immediately it again comes in contact with the common air of the chamber, unites with the oxygen and reforms nitrous acid, which again meeting with sulphurous, once more forms crystals, and is deprived of its oxygen as before, thus constantly acting as a carrier of oxygen from the atmospheric air to the sulphurous acid as long as any of these two substances remains in the chamber. To prove the truth of this theory, Mr. Dalton contrived the following beautiful and satisfactory experiment²:

² *New System of Chemical Philosophy*, page 396.

“ Let 100 measures of sulphurous acid gas be put into a dry tube over mercury, to which add 60 of oxygen gas; let then 10 or 20 measures of nitrous gas (nitric oxide) be added to the mixture; in a few seconds the inside of the tube becomes covered with a crystalline appearance, like hoar-frost, and the mixture is reduced to one-third or one-fourth of its original volume. If now a drop of water be admitted, the crystalline matter is quickly dissolved in the water, sparkling as it enters, and the gases entirely lose their elasticity, except a small residuum of azote and nitrous gas. If the tube be then washed out, the water tastes strongly acid, but has no smell of sulphurous acid. It is evident, that in this process the nitrous gas unites to the oxygen, and transports it to the sulphurous acid, which, receiving it from the nitrous gas, becomes sulphuric acid. It appears, moreover, that solid sulphuric acid is formed when no water is present; and consequently this is the natural state of sulphuric acid entirely free from water.”

Sir H. Davy, however, discovered that nitric oxide has no action whatever on sulphurous gas, unless moisture be present, but that with a very small proportion of water they form a white crystalline matter, which is instantly decomposed by the addition of more water, with the extrication of nitric oxide; and this by the contact of atmospheric air, or oxygen, becomes nitrous acid as before.

When sulphuric acid is pure, it is entirely devoid of colour and smell; it is extremely acid and corrosive, and one of the most ponderous fluids we are acquainted with. It is capable of uniting with the earths, the alkalies, and most of the metallic oxides, and in these combinations it forms those salts which are known by the name of sulphates.

Having said that sulphuric acid is corrosive, I am desirous, before I proceed to mention its other properties, of observing that instances may occur of its being taken into the stomach by mistake, and without immediate relief its corrosive properties would produce fatal effects. If magnesia should be at hand, that earth mixed with water and sweetened with sugar, would be the best possible antidote to the poison; but in case this could not be immediately procured, soap-water, which can be furnished by all families, and which is one of the next best remedies, should be drunk plentifully. The unfortunate death of an infant son of the Hon. and Rev. E. Knox, at Dungarvon Park, in consequence of his swallowing a quantity of oil of vitrol which had been carelessly left on the table by a female domestic, shows how important it is for the public to be acquainted with the proper remedy in such cases.

The most distinguishing characteristics of sulphuric acid are,

its peculiar affinity for barytes, which it is capable of separating from all other combinations; and its attraction for water, which it absorbs with great avidity, even from the atmosphere, whenever it is exposed to it in a state of concentration. The attraction which sulphuric acid has for water is so powerful, that in certain operations of the laboratory it is often employed for the purpose of creating a dry atmosphere.

The great affinity of sulphuric acid for water may be shown by the following very easy experiment:—If the bulb of a thermometer be dipped in concentrated sulphuric acid, it will probably not be perceived that the immersion has occasioned any alteration in the temperature of the thermometer; but if it be withdrawn and held in the open air, the small portion of acid which adheres to the bulb will absorb water from the atmosphere with so much rapidity (especially if it be in damp weather) that in a few seconds the mercury in the thermometer will be seen to rise several degrees.

The mixture of sulphuric acid and water occasions a great extrication of caloric. If a thermometer be placed in a glass of water, and concentrated sulphuric acid gradually added, the mercury will instantly begin to ascend, and progressively to a certain extent; and if two pounds of this acid be suddenly mixed with one pound of water, the temperature will immediately be raised much higher than that of boiling water¹. No advantage seems, however, to have been taken of this property of sulphuric acid, though it affords the means of furnishing a variety of degrees of heat in an instant. Indeed, the rapidity with which the temperature becomes afterwards reduced, would probably be an obstacle to its employment in any of the operations of the laboratory, or in the affairs of common life. I have, however, as a matter of curiosity, constructed the following table of the different temperatures which are produced by the mixture of water in various proportions with this acid.

The temperatures of the water which I employed and of the atmosphere of the room were both at 50°. The acid was the common oil of vitriol of commerce at the temperature of 56°, and of the specific gravity of 1.844, and fresh oil of vitriol and fresh water were taken for every distinct experiment.

The effect produced by the mixture of sulphuric acid and water is well known; but no writer has noticed the property which heated sulphuric acid has of retaining its caloric, or of imparting it more slowly than most other fluid bodies usually do.

¹ On the contrary, it may be remarked, that if two pounds of diluted sulphuric acid be mixed with three pounds of snow, the temperature of the snow will immediately be reduced 55 degrees, or from 32° to -23°.

I have observed that the workmen frequently pour this article from the retorts into large empty glass bottles called carboys, at a temperature of from 190° to 200° without inconvenience; whereas, if water were used at the same, or even at a lower temperature, it would not fail to split them in an instant.

I. A Table of the Temperatures produced by the Mixture of Sulphuric Acid and Water; 10lbs. avoirdupois of water being used in each experiment.

Sulph. acid in pounds.	Acquired Temper. of Fahrenht.	Sulph. acid in pounds.	Acquired Temper. of Fahrenht.	Sulph. acid in pounds.	Acquired Temper. of Fahrenht.	Sulph. acid in pounds.	Acquired Temper. of Fahrenht.
1	78°	7	156°	13	229°	19	256°
2	100	8	168	14	236	20	258
3	110	9	186	15	241	25	266
4	128	10	204	16	246	*30	264
5	138	11	214	17	250	35	254
6	144	12	222	18	253	40	248

In making these experiments, I observed that in the first two it required five minutes for the mixture to arrive at the maximum of temperature; that afterwards it acquired the maximum in two minutes; and that when the weight of the sulphuric acid was more than half that of the water with which it was mixed, the heat was evolved with still greater rapidity, till at last the change seemed to be instantaneous.

The accurate performance of these experiments is attended with some difficulty, on account of the steam which arises from the surface of the mixture; for when the weights of the sulphuric acid exceeded those of the water, the steam, in some of the experiments, was so great as to render it very difficult to determine the exact point to which the mercury had ascended. In the latter experiments, when the weight of the acid amounted to nearly double that of the water, although the temperature occasioned by the mixture of those fluids was higher, little or no vapour was formed, and the graduation of the thermometer could, at each experiment, be observed with exactness.

Fourcroy, in his *System of Chemical Knowledge*, relates¹ that "the mixture of water and sulphuric acid which produces the greatest heat, consists of four parts of acid and one of water, and that the temperature rises to 120° of Reaumur's scale," equal to 302° of Fahrenheit. This statement I find to be incorrect; for

* An experiment was made with the same proportion of the ingredients in ounces instead of pounds: viz. ten ounces of water at 50° were mixed with thirty ounces of sulphuric acid at 56° ; and though the mixture was made in favourable circumstances, the temperature did not exceed 246° of Fahrenheit;

¹ Nicholson's *Translation of Fourcroy*, vol. ii. page 94.

the real maximum of temperature is obtained by a mixture of between two and three parts of acid to one of water; and the greatest elevation of temperature which I have been able to procure, is that of 266° . Had the experiments, however, been made in summer, it is probable the temperature might have been raised some degrees higher.

It may be necessary to caution those who have not been accustomed to chemical operations, and yet would like to repeat these experiments, to be careful to add the acid to the water, and not to reverse it by pouring the water upon the acid, which would be apt to occasion a part of the mixture to fly up, and endanger the face and the clothes of the operator.

Several years ago, I was frequently applied to by persons in different parts of the kingdom, for instructions respecting some mode of ascertaining the quantity of acid in diluted sulphuric acid of various specific gravities; and I invariably referred them to Dr. Kirwan's Table, which was published in the year 1793 in the fourth volume of the *Transactions of the Royal Irish Academy*. This, however, generally proved unsatisfactory to those who applied to me, inasmuch as few manufacturers could understand how to accommodate that table to the common oil of vitriol, or make it applicable to any practical purpose. This has arisen from the circumstance of Dr. Kirwan having taken for his standard sulphuric acid as it exists in sulphate of potash, instead of employing the oil of vitriol of commerce.

Having found the inconvenience of this in my own concerns, I long ago formed a table for private use, founded upon the sulphuric acid of commerce, by diluting that acid with several successive portions of water; a table which I employed for several years with great advantage. But as this table was formed at a temperature above the mean temperature of the atmosphere, and its range was too confined to be of use in every instance, I resolved to undertake the formation of a new one that would be more generally useful, and which should proceed by very slow but regular gradations up to the highest point of dilution that any consumer of sulphuric acid would be likely to require².

Having at no small expense of time and labour completed this table, it will be inserted in this Essay, from a persuasion that it will prove useful to many individuals in various branches of trade and manufacture.

To compose this table, I might have taken *purified* sulphuric acid, *i. e.* such as had undergone an actual distillation; but as

² The first line of the table shows the specific gravity of a mixture of one part water and 100 parts of strong sulphuric acid. The latter, the specific gravity of one part of sulphuric acid mixed with 100 parts of water.

this is an article which is never employed but for philosophical purposes, I thought it better to make use of the common acid, and to take as good a sample of that kind as could possibly be procured. I therefore chose some of my own manufacture, made in the usual way, and concentrated, as is common in large manufactories, by steaming it in a boiler of lead, and finishing it in a retort of glass. When I began the experiments of dilution, the atmosphere of the room was 60° , and the acid was of the specific gravity of 1.8494, which at this temperature¹ is as strong as it is ever sold.

In order to form the annexed table, I proceeded as follows :

I first accurately weighed ten thousand grains of the acid into a stoppered bottle of glass, and then added to it 100 grains of pure water. When the mixture was become cool, after having been sufficiently agitated, the specific gravity of it was taken, and the result forms the first line of the table. In this way I continued to dilute the acid with successive portions of water, taking care to let it rest a sufficient time between each addition of the water, that a complete union between the acid and the water might take place; having found by experiment that a mixture of sulphuric acid and water, even after it has become cold, requires several hours to arrive at the maximum of condensation. I took also the precaution of keeping it in stoppered bottles, that it might not imbibe water from the atmosphere, and frequently agitated it during each interval. And in order to attain as great accuracy as possible, I procured a specific-gravity-bottle larger than usual, one that holds nearly ten ounces of water, and with a stem so small that at the part to which the fluid rises when properly filled, a single drop of the liquor will occasion a rise of nearly one-sixteenth of an inch.

The balance which I made use of in these experiments will turn with the twentieth part of a grain; and as the acids will erode the common scale-dishes, if dropt upon them, and endanger the accuracy of a result, I have long been in the habit of using those made of Wedgwood's ware, and such were employed in making this table. Those parts of the table which have a star opposite to them, were founded on actual experiment; the intermediate ones were the results of calculation.

Since I concluded these experiments it occurred to me, that it might be useful to some manufacturers to know the quantity of acid per cent. in diluted acid of any given strength; I have therefore calculated the quantity in each, and annexed it. The column of *ounces* and *drachms* is added for the use of those who are accustomed to this mode of reckoning, and also for those who are

¹ For the difference which is occasioned in the specific gravity of sulphuric acid by change of temperature, consult Table III. in this Essay.

not conversant with the usual method of stating specific gravities; and it is calculated on the supposition of the wine-pint holding exactly sixteen ounces avoirdupois of pure water.

It is a convenient way of measuring, to have a glass bottle with a narrow neck, holding rather more than a pint of water, with a mark on the stem at the place to which the water ascends when it contains exactly 16 ounces avoirdupois of that fluid. It was formerly understood that the standard wine-pint was the exact measure of 16 ounces of pure water; but in opposition to a decision made by the Board of Excise in the year 1688, it has since been determined that the English wine-pint holds 7272 grains of pure water, which is 272 grains more than an avoirdupois pound. However, as it has long been usual, for all common purposes, still to consider it of the capacity of 16 ounces avoirdupois, I have taken it at that in the construction of this table.

If the wine-pint of water (7272 grains) be divided by 16, this will give $454\frac{1}{2}$ grains for the weight of the ounce measure of water, which if expressed in decimal figures will stand thus, 454.5; and it is worth remarking, that there is a singular coincidence here which is very favourable to the memory, *viz.* the pint measure is *seven two—seven two*; and the ounce measure, *four five—four five*.

The sulphuric acid which is consumed in these kingdoms amounts to upwards of three thousand tons annually, of which the greater part is used in a state of dilution. For the purposes of dissolving iron or zinc, it should be diluted with at least five or six times its weight of water. Sulphuric acid is consumed in large quantities by bleachers, for making the chloride of lime, and they always use it in a state of dilution. The calico-printers also use this acid, in various states of dilution, for making what they call *sours*.

To these and other manufacturers this table will be of use, not only in assisting them in the formation of diluted acid of any given strength, but it will enable them at any time to ascertain whether their servants have observed due care in making the different preparations, which is a matter of great moment; for it often happens, that for want of this the printer and manufacturer suffer great loss, and the printed goods sustain an irreparable injury.

I need scarcely add that the sulphuric-acid-makers themselves may also derive benefit from attending to this table; for by its assistance they can at all times form a pretty accurate estimate of the value of any sample of the unrectified acid, or of the weak acid while in the state of operation in any of their leaden chambers.

II. A Table of the Specific Gravities of Sulphuric Acid, when diluted with different portions of water, constructed for the use of manufacturers; being the result of experiments made with the strongest sulphuric acid of commerce. The specific gravities taken at the temperature of 60°; and 100 drachms of sulphuric acid, sp. gr. 1.8494, used in each experiment.

Drachms of Water.	Specific Gravity.	Weight of the Wine-pint. Oz. Drms.	Acid per Cent.	Drachms of Water.	Specific Gravity.	Weight of the Wine-pint. Oz. Drms.	Acid per Cent.
*1	1.8484	29 9 $\frac{1}{4}$	99.009	49	1.5645	25 0 $\frac{1}{2}$	67.114
*2	1.8465	29 8 $\frac{3}{4}$	98.039	50	1.5585	24 15	66.666
*3	1.8445	29 8 $\frac{1}{4}$	97.087	51	1.5526	24 13 $\frac{1}{2}$	66.225
*4	1.8416	29 7 $\frac{1}{2}$	96.153	52	1.5478	24 12 $\frac{1}{4}$	65.789
*5	1.8387	29 6 $\frac{3}{4}$	95.238	53	1.5429	24 11	65.359
6	1.8358	29 6	94.339	*54	1.5390	24 10	64.935
*7	1.8319	29 5	93.457	55	1.5351	24 9	64.516
8	1.8270	29 3 $\frac{3}{4}$	92.509	56	1.5312	24 8	64.102
9	1.8222	29 2 $\frac{1}{2}$	91.743	57	1.5273	24 7	63.694
*10	1.8163	29 1	90.909	58	1.5234	24 6	63.291
11	1.8104	28 15 $\frac{1}{2}$	90.090	59	1.5195	24 5	62.893
12	1.8046	28 14	89.285	60	1.5156	24 4	62.500
13	1.7988	28 12 $\frac{1}{2}$	88.495	61	1.5117	24 3	62.111
14	1.7929	28 11	87.719	*62	1.5078	24 2	61.728
*15	1.7880	28 9 $\frac{3}{4}$	86.956	63	1.5039	24 1	61.349
16	1.7821	28 8	86.206	64	1.5000	24 0	60.975
17	1.7744	28 6 $\frac{1}{4}$	85.470	65	1.4960	23 15	60.606
18	1.7666	28 4 $\frac{1}{4}$	84.745	66	1.4921	23 14	60.240
19	1.7588	28 2 $\frac{1}{4}$	84.033	67	1.4882	23 13	59.880
20	1.7510	28 0 $\frac{1}{4}$	83.333	68	1.4843	23 12	59.523
*21	1.7431	27 14 $\frac{1}{4}$	82.644	69	1.4804	23 11	59.171
22	1.7353	27 12 $\frac{1}{4}$	81.967	*70	1.4765	23 10	58.823
23	1.7275	27 10 $\frac{1}{4}$	81.300	71	1.4726	23 9	58.481
24	1.7207	27 8 $\frac{1}{2}$	80.645	72	1.4687	23 8	58.139
25	1.7138	27 6 $\frac{3}{4}$	80.000	73	1.4648	23 7	57.803
26	1.7070	27 5	79.365	74	1.4609	23 6	57.471
*27	1.7002	27 3 $\frac{1}{4}$	78.740	75	1.4570	23 5	57.142
28	1.6933	27 1 $\frac{1}{2}$	78.125	76	1.4531	23 4	56.818
29	1.6865	26 15 $\frac{3}{4}$	77.519	77	1.4502	23 3 $\frac{1}{4}$	56.497
30	1.6796	26 14	76.923	*78	1.4473	23 2 $\frac{1}{2}$	56.179
31	1.6728	26 12 $\frac{1}{4}$	76.335	79	1.4433	23 1 $\frac{1}{2}$	55.865
32	1.6660	26 10 $\frac{1}{2}$	75.757	80	1.4395	23 0 $\frac{1}{2}$	55.555
*33	1.6582	26 8 $\frac{1}{2}$	75.187	81	1.4365	22 15 $\frac{3}{4}$	55.248
34	1.6523	26 7	74.626	82	1.4336	22 15	54.945
35	1.6464	26 5 $\frac{1}{2}$	74.074	83	1.4306	22 14 $\frac{1}{4}$	54.644
36	1.6406	26 4	73.529	84	1.4276	22 13 $\frac{1}{2}$	54.347
37	1.6348	26 2 $\frac{1}{2}$	72.992	85	1.4257	22 12 $\frac{3}{4}$	54.054
38	1.6289	26 1	72.463	*86	1.4218	22 12	53.763
39	1.6230	25 15 $\frac{1}{2}$	71.942	87	1.4189	22 11 $\frac{1}{4}$	53.475
*40	1.6171	25 14	71.428	88	1.4160	22 10 $\frac{1}{2}$	53.191
41	1.6113	25 12 $\frac{1}{2}$	70.921	89	1.4130	22 9 $\frac{3}{4}$	52.910
42	1.6054	25 11	70.422	90	1.4101	22 9	52.631
43	1.5995	25 9 $\frac{1}{2}$	69.930	91	1.4072	22 8 $\frac{1}{2}$	52.356
44	1.5937	25 8	69.444	92	1.4042	22 7 $\frac{1}{2}$	52.083
*45	1.5879	25 6 $\frac{1}{2}$	68.965	93	1.4013	22 6 $\frac{3}{4}$	51.813
46	1.5820	25 5	68.493	*94	1.3984	22 6	51.546
47	1.5761	25 3 $\frac{1}{2}$	68.027	95	1.3955	22 5 $\frac{1}{4}$	51.282
48	1.5703	25 2	67.567	96	1.3926	22 4 $\frac{1}{2}$	51.020

Drachms of Water.	Specific Gravity.	Weight of the Wine-pint. Oz. Drms.	Acid per Cent.	Drachms of Water.	Specific Gravity.	Weight of the Wine-pint. Oz. Drms.	Acid per Cent.
97	1.3906	22 4	50.761	*420	1.1328	18 2	19.230
98	1.3886	22 3½	50.505	440	1.1279	18 0¾	18.518
99	1.3867	22 3	50.256	*460	1.1240	17 15¾	17.857
*100	1.3848	22 2½	50.000	480	1.1181	17 14¼	17.241
105	1.3730	21 15½	48.780	*500	1.1132	17 13	16.666
*110	1.3632	21 13	47.619	*550	1.1054	17 11	15.384
115	1.3535	21 10½	46.511	*600	1.0966	17 8¾	14.285
*120	1.3437	21 8	45.454	*650	1.0898	17 7	13.333
125	1.3359	21 6	44.444	*700	1.0839	17 5½	12.500
*130	1.3281	21 4	43.478	*750	1.0781	17 4	11.764
135	1.3203	21 2	42.553	*800	1.0732	17 2¾	11.111
*140	1.3125	21 0	41.666	*850	1.0693	17 1¾	10.526
145	1.3056	20 14¼	40.816	*900	1.0664	17 1	10.000
*150	1.2988	20 12½	40.000	*950	1.0625	17 0	9.523
155	1.2919	20 10¾	39.215	*1000	1.0602	16 15½	9.090
*160	1.2851	20 9	38.461	*1100	1.0546	16 14	8.333
165	1.2783	20 7½	37.735	*1200	1.0507	16 13	7.692
170	1.2724	20 5¾	37.037	*1300	1.0488	16 12½	7.142
175	1.2676	20 4¾	36.363	*1400	1.0458	16 11¾	6.666
*180	1.2627	20 3½	35.714	*1500	1.0429	16 11	6.250
185	1.2568	20 1¾	35.087	1600	1.0390	16 10	5.882
190	1.2520	20 0¾	34.482	1700	1.0370	16 9½	5.555
195	1.2470	19 15¼	33.898	*1800	1.0351	16 9	5.263
*200	1.2421	19 14	33.333	1900	1.0337	16 8⅝	5.000
210	1.2343	19 12	32.258	*2000	1.0322	16 8¼	4.761
*220	1.2265	19 10	31.250	*2250	1.0283	16 7¼	4.255
230	1.2187	19 8	30.303	*2500	1.0254	16 6½	3.846
*240	1.2129	19 6½	29.411	*2750	1.0234	16 6	3.508
250	1.2060	19 4¾	28.571	*3000	1.0214	16 5½	3.225
*260	1.1992	19 3	27.777	*3500	1.0185	16 4¾	2.777
270	1.1933	19 1½	27.027	*4000	1.0166	16 4¼	2.439
*280	1.1875	19 0	26.315	*4500	1.0146	16 3¾	2.173
290	1.1825	18 14¾	25.641	*5000	1.0127	16 3¼	1.960
*300	1.1776	18 13½	25.000	5500	1.0117	16 3	1.785
310	1.1728	18 12¾	24.390	*6000	1.0107	16 2¾	1.639
320	1.1679	18 11	23.809	*6500	1.0102	16 2⅝	1.515
330	1.1630	18 9¾	23.255	*7000	1.0098	16 2½	1.408
*340	1.1582	18 8½	22.727	7500	1.0093	16 2⅜	1.315
350	1.1552	18 7¾	22.222	*8000	1.0088	16 2¼	1.234
360	1.1523	18 7	21.739	8500	1.0083	16 2⅛	1.162
370	1.1494	18 6½	21.276	*9000	1.0078	16 2	1.098
*380	1.1464	18 5½	20.833	9500	1.0073	16 1⅞	1.041
390	1.1426	18 4½	20.408	*10000	1.0068	16 1¾	0.990
400	1.1338	18 2¼	20.000				

This table was compiled in the year 1812, and printed in the *Phil. Mag.* for the September of that year; but since its publication I have been informed there is a table by Vauquelin in vol. 76, page 260, of the *Annales de Chimie*, on a similar plan. To this I have referred; and on comparison, allowing for the difference in the strength of the acid which we severally employed, I find that his table and mine very nearly coincide, except in one instance, and in this there is a very material disagreement. His

table, however, is a very confined one, for it affords only twelve examples of the specific gravity of diluted sulphuric acid; whereas mine contains no less than 183 such examples.

In my table it is stated that the diluted acid of the specific gravity of 1.023 contains only 3.508 per cent. of the strongest sulphuric acid of commerce; whereas he says it contains 6.600 per cent. of acid and 93.400 of water. This has induced me to repeat so much of the experiment as was necessary for satisfaction on this point, and I find that this repetition only confirms the accuracy of the experiments on which my table was founded.

However, as the sulphuric acid which Vauquelin employed had a specific gravity only of 1.8420, I procured some acid exactly of the same strength; and having carefully mixed 66 drachms of it with 934 drachms of pure water, both measured by weight, and left the mixture at rest a proper time for a complete combination to be effected, I found its specific gravity at 60° of Fahrenheit to be 1.0474, instead of 1.0230 as Vauquelin has stated. Pursuing the experiment still further, I found that 66 drachms of such acid, instead of taking 934 drachms of water, actually require 2084 drachms of that fluid to reduce the whole to the specific gravity in question, viz. that of 1.023.

As the foregoing table proceeds entirely on the dilution of the concentrated sulphuric acid with different portions of water, it will not be misplaced if I add a caution respecting the *keeping* of this acid in a state of dilution, which in certain cases is highly dangerous.

Some years ago, being in conversation with a sulphuric-acid-maker, I inadvertently remarked that this acid might be rendered colourless and pellucid without submitting it to the process of rectification in glass, and I told him how the thing might be effected.

Delighted with this intelligence, on his return home he immediately put the process to the test, without having previously communicated his intention to his partner, and he actually prepared more than one hundred carboys, holding about 150lbs each, of this weak acid, in readiness to be sent off to customers whom he had hitherto supplied with the usual sulphuric acid of commerce, and who would not, as he imagined, perceive the difference.

But, unfortunately for this crafty individual, it was in the midst of winter when this grand scheme of sophistication was adopted, and every carboy which he had prepared became frozen. Bottle after bottle, therefore, burst by the expansion of the acid in the act of freezing; and if he had not adopted the method of filling all the large vessels on the premises with tepid water, and immer-

sing the packed carboys in it, not a single bottle would have been saved from the general wreck.

To prevent accidents from the inadvertent mixture of water with oil of vitriol, it cannot be too generally known, that sulphuric acid diluted to the specific gravity of 1.780, which is twenty-eight ounces and a half to the wine-pint, will freeze *much sooner* than water ¹. If 12 or 13 per cent. of water be mixed with the strongest sulphuric acid of commerce, it will form an acid of about this specific gravity, and such acid would freeze at some degrees of temperature higher than that at which water congeals. Mr. Dalton has, however, by experiment ascertained a curious fact which had been hinted by Mr. Keir, respecting the dilution of sulphuric acid ², viz. that if the liquid acid be of greater or less specific gravity, so as to contain even one per cent. more or less real acid, in that case it cannot be frozen in a temperature above 32°.

It was known to many of the old chemists that concentrated sulphuric acid would congeal at a very low temperature; but this very curious and singular property respecting the dilution of sulphuric acid was first noticed in this country by Mr. Keir.

From the experiments of this eminent chemist, it appears that there is a certain degree of strength at which sulphuric acid proves more congealable even than water. He exposed concentrated sulphuric acid to a frosty air in *open* vessels, and when it had imbibed enough water from the atmosphere to reduce it to about 1.780 it became congealed, and the congealed part, when thawed, was found to be of the standard of easiest freezing. Afterwards, in another experiment, he found the congealed part to thaw, in the open air, even while the cold increased, the continued absorption of moisture having weakened it below the degree of congelation. It is of importance that these facts should be known by all persons who either manufacture or employ sulphuric acid.

The affinities of sulphuric acid are in the following order:—Barytes, Strontites, Potash, Soda, Lime, Magnesia, Ammonia.

The boiling point of the best sulphuric acid of commerce, viz. that of 1.848, according to Mr. Dalton, on whom the utmost reliance may be placed, is 590° of Fahrenheit; but if it contain one per cent. more of acid, which would give it a specific gravity of 1.849, the boiling point will be raised to 605°; and if at the temperature of 60° it be one degree higher, viz. 1.850, it will not boil until it be heated to 620°.³

In a commercial point of view, and for every purpose of philo-

¹ Keir, *Philosophical Transactions*, part ii. for 1787.

² See *New System of Chemical Philosophy*, page 406.

³ Dalton's *Chemical Philosophy*, page 404.

sophical chemistry, it is of importance to become acquainted with the variations in the specific gravity of this acid in consequence of change of temperature. I know, however, of no one except Kirwan who has given any information on the subject; and in my opinion he has been peculiarly unfortunate in having made choice of *diluted* acid for his experiments, instead of the best concentrated acid¹. For to most persons, and especially those who are large buyers of sulphuric acid, it must surely be of more importance to know what the strong sulphuric acid of commerce ought to be in all the variety of temperatures to which this climate is liable. To supply this desideratum, I undertook a series of experiments with such acid, and the several results have enabled me to construct the following table; which, in order that it might embrace every possible exigency, has been extended to 192 degrees of Fahrenheit.

III. A Table of the Variations in the Specific Gravity of concentrated Sulphuric Acid, by change of Temperature. Barometer 29.5 inches.

Temperature according to Fahrenheit.	Contents in Grains of a bottle holding 4266 grains of pure water, at 42.5 deg. of Fahrenheit.	Specific Gravities.	Temperature according to Fahrenheit.	Contents in Grains of a bottle holding 4266 grains of pure water, at 42.5 deg. of Fahrenheit.	Specific Gravities.
10°	8000	1.8752	80°	7816	1.8381
20	7964	1.8668	84	7794	1.8343
24	7952	1.8640	88	7788	1.8346
27	7940	1.8612	92	7780	1.8349
30	7932	1.8593	96	7772	1.8343
32	7920	1.8565	102	7748	1.8308
36	7912	1.8546	108	7729	1.8280
38	7906	1.8532	112	7720	1.8267
40	7904	1.8527	120	7710	1.8270
42	7901	1.8520	126	7702	1.8277
44	7898	1.8522	134	7692	1.8279
46	7895	1.8519	140	7676	1.8280
48	7892	1.8517	146	7648	1.8248
52	7886	1.8511	154	7632	1.8258
56	7880	1.8501	162	7610	1.8240
60	7864	1.8468	170	7582	1.8225
63	7854	1.8449	178	7567	1.8233
68	7846	1.8435	184	7558	1.8247
70	7842	1.8430	192	7546	1.8271
74	7833	1.8413			

It must be understood, that in forming this table the low degrees of temperature were produced by immersing a vessel containing the sulphuric acid in a frigorific mixture of snow and

¹ The account of these experiments by Dr. Kirwan, may be seen in Nicholson's *quarto Journal*, vol. iii. page 211.

muriate of soda; and that the high temperatures were obtained by gradually heating the specific-gravity-bottle, containing the same acid, before a common fire. Some allowance must therefore be made for the contraction and expansion of the glass, and which would, in some measure, alter the capacity of the containing vessel; but this is unavoidable. In each experiment the acid was poured from the phial, and thoroughly mixed, in order to be sure that the temperature was uniform before the thermometer was immersed in it.

From these experiments it appears that a vessel capable of containing 8000 grains of concentrated sulphuric acid at 10° of Fahrenheit, will not hold more than 7546 grains of this acid if at the temperature of 192° , and that sulphuric acid which is of the specific gravity of 1.8752 at 10° , will become of the specific gravity of 1.8271 when brought within 20 degrees of the temperature of boiling water.

It must, however, be remarked, that the chief design in constructing this table was to furnish the buyers and sellers of sulphuric acid with a scale by which they might ascertain the proper specific gravity of this acid at all temperatures. For instance, 1.845 is well known to be the proper strength at the temperature of 63° ; but by the inspection of this table it will appear, that, when the atmosphere has for some time been at the temperature of 36° , such acid must be deficient in strength if it does not reach the specific gravity of 1.8546.

It has been ascertained that the maximum density of water is at the temperature of $42^{\circ} 5$, and that it becomes specifically lighter, whether it be heated above or cooled below that point. In making the foregoing table therefore, it was necessary in the first place to fix the weight of the bottle of pure water at the temperature of $42^{\circ} 5$. This I found to be 4266 grains, and this I made the divisor in every case from 10° up to 42° inclusive. After this the weight of the water was taken at 44° , and at every other degree between that and 192° ; and in calculating the specific gravity of the sulphuric acid at 44° , and at all the higher temperatures, the weight of the acid in every instance was divided by the weight of the same measure of water at the corresponding temperature. This method of constructing the table (and I could not devise any other that would not have presented still greater difficulties) will perhaps account for several anomalies in the specific gravities of the acid when heated above 84° . For instance, the acid at 96° appears to have the same relative weight as at the temperature of 84° ; also the acid at 108° and at 140° , seems to have the same specific gravity. This irregularity may be accounted for by supposing that sulphuric acid in its expansion, observes a different law from that of pure water, which, in

the formation of this table, as has been before noticed, was made the divisor in every instance ¹.

Mr. Dalton has remarked that "it is a mistaken notion, that the common sulphuric acid of commerce is of the maximum strength, though it is of the maximum density nearly. The fact is, acid nearly of the maximum strength varies very little in its specific gravity, by the addition or subtraction of a small quantity of water. The specific gravity ought not therefore to be the criterion of strength in acids above 70 per cent.; the temperature at which they boil is a much better criterion, because it admits of a range of 12° or 15° for one per cent. of acid. Or the strength may be found by determining what quantity of water must be added to reduce the acid to some known strength, as that of the glacial acid, of 1.78 specific gravity."

The subject must not be dismissed without adverting to the **USES** of this acid.—The **USES** of sulphuric acid are very numerous. It is employed in large quantities, as has been already mentioned, for preparing bleaching-powder; by dyers for dissolving indigo, and for other purposes; by calico-printers for preparing sours; and by the manufacturing and the philosophical chemist, as a test for lead and barytes, and for a great variety of other purposes, some of which only can be enumerated.

The makers of the nitric and muriatic acids are large consumers of sulphuric acid; as also are the makers of sulphate of zinc, sal-ammoniac, phosphate of soda, Glauber's and other salts; as well as the manufacturers of Roman vitriol, Prussian blue, and some other colours.

Sulphuric acid is likewise employed by some modern farmers in the preparation of their seed-wheat, to prevent what is called the smut; by manufacturers of the citric and tartaric acids, and by the makers of glass to convert the muriate of potash, which is one of their residuums, into sulphate of potash, an article which has lately been used by them as a substitute for soda. It is also consumed in large quantities by the manufacturers of tin-plate, by brass-founders, button-makers, japanners and gilders; to all of whom this acid is become absolutely necessary for the removal of the oxide which forms on the surface of the iron or the copper on which they work, and which, if not removed, would prevent or impede all their operations.

Sulphuric acid is likewise a necessary article to some paper-makers, to fell-mongers, and to tanners;—it is used in considerable quantities by the modern hatter in the operation of

¹ A new table of the expansion of water by increase of temperature, will be given in the Essay on Water.

felting²;—and it may be mentioned that refiners use it in the process of stripping metals;—oil-merchants, in refining rape-oil, which it effects by carbonizing the farinaceous matter and the mucilage;—and brewers in fining what is called *gray beer*:—that the professors of pharmacy as well as the chemists are constant customers for sulphuric acid;—that it is employed in making the astringent and stomachic water of Rabel³, and for other purposes of medicine as well as surgery;—that distillers and rectifiers of ardent spirits consume it in still larger quantities;—and that many tons are annually consumed in the preparation of liquid blacking.

It has occurred to me that it may be useful to be able to see at one view what minerals and native salts there are which contain sulphuric acid.—I have therefore made out the following list, omitting such as afford a trace only, or a very small quantity of this acid.

Sulphate of ALUMINA, or native alum.—This occurs on an estate belonging to Mr. Mackintosh at Hurlet, near Paisley, and as an incrustation on the alum-slate of Whitby in Yorkshire. It is found also in Norway, in Bohemia, and in other places in Europe, Africa, and America. There is another species found at Hurlet, called Rock-butter, which is a native alum, mixed with alumina and oxide of iron. A specimen which he calls plumose alum, from Brandenburg, was analysed by Klaproth, and found to consist of alumina 15.25, oxide of iron 7.50, potash 0.25, sulphuric acid and water of crystallization 77.0.

The specimens of alum-slate from Hurlet have the most beautiful incrustations of plumose alum that can be conceived.

Alum-stone contains from 12 to 25 per cent. of sulphuric acid, and the mineral called *native argil* or *aluminite*, 21 per cent. of this acid.

Mascagnine, or native sulphate of AMMONIA.—This mineral substance occurs among the products of Etna and Vesuvius, and is also obtained from certain districts in Tuscany. Karsten named it Mascagnine from its discoverer Professor *Mascagni*. Its colours are yellowish-gray and lemon-yellow⁴. One hundred parts, according to Kirwan⁵, contain ammonia 29.7, sulphuric acid 55.7, water 14.16.

Sulphate of BARYTES.—This native production has already been amply described at pages 122 and 147 of this volume. Some of

² See an explanation of this in Essay I, page 21.

³ See Fourcroy's *System of Chemistry*, vol. viii. page 240.

⁴ Jameson, vol. ii. page 339.

⁵ Kirwan's *Mineralogy*, vol. ii. page 10.

the crystals of this mineral are extremely beautiful. According to Withering, it is a compound of 32.8 sulphuric acid, and 67.2 barytes. A specimen from Berlin in Connecticut¹ was found to consist of

Pure barytes	57.33	Silica	2.50
Pure strontites	3.92	Oxide of iron and alumina	1.75
Sulphuric acid	33.50	Water	1.00

The native sulphate of barytes of Europe is found to vary in its composition according to the places from whence it is obtained.

Celestine, or native sulphate of STRONTITES.—This mineral is found at Inverness; in Yorkshire; and at other places in Great Britain; more particularly at Aust Passage in the neighbourhood of Bristol. Klaproth's analysis makes it to consist of 56 strontites, and 42 sulphuric acid.

Some very fine specimens of crystallized sulphate of strontites have been procured from Strontian Island, Lake Erie, in the United States of America².

Sulphate of COBALT.—This is a native salt which has been found near Hanau in Germany. Its colour is a light flesh-red. It has a very caustic taste, and is soluble in water. It is a compound of sulphuric acid 19.74 + oxide of cobalt 38.71 + water 41.55 = 100 sulphate of cobalt. This analysis was made by M. Kopp, an account of which was published by Bucholz, with the analysis of other minerals³.

Sulphate of COPPER, or native blue vitriol.—This mineral occurs in Pary's mine in the Isle of Anglesea; in the county of Wicklow in Ireland; and also in many other of the copper mines of Europe. Its colour is dark sky-blue. According to Berzelius it is composed of oxide of copper 32.13 sulphuric acid 31.57 water 36.30 = 100 sulphate of copper.

Glauberite.—This mineral is found imbedded in rock-salt at Villaruba, near Ocana in New Castile, in Spain. It was first analysed by Brongniart⁴. He found it to be composed of sulphate of lime 49, and sulphate of soda 51.

Pitchy IRON Ore, or the pitchy bog-iron ore of Aikin.—This mineral occurs in a mine near Freyberg, and in the district of Plessin Upper Silesia. Klaproth has analysed it, and found it to consist of⁵ oxide of iron 67, and sulphuric acid and water 33.

¹ American *Journal of Science*, vol. iv. page 327.

² Silliman's *Journal*, vol. iv. page 279.

³ *Annales de Chimie*, vol. lxx. page 55.

⁴ Jameson, vol. ii. page 255.

⁵ Phillips's *Elements*, page 209.

IRON vitriol, or native sulphate of iron, occurs under a variety of forms in several coal-mines in this country and on the continent of Europe. A specimen of native sulphate of iron was analysed by Berzelius, and found to consist of oxide of iron 25.7, sulphuric acid 28.9, and water of crystallization 45.4.

LEAD vitriol, or native sulphate of lead, occurs at Penzance in Cornwall, at Pary's mine in the Isle of Anglesea, and at Lead-hills in Scotland. It is found also in Siberia and in the United States of America. A specimen from the Lead-hills was found by Klaproth⁶ to consist of oxide of lead 70.50, sulphuric acid 25.75, and water of crystallization 2.25.

Sulphate of LIME is a mineral that is procured in great abundance at Chelaston near Derby, and at Beacon-hill near Newark. It is a compound of 32 lime, 30 of sulphuric acid, and 38 water. It is found also in various parts of North America, where it is employed as a manure. The *Anhydrite*, or *Muriacit* of Werner, contains a still larger portion of sulphuric acid. A specimen analysed by Klaproth was found to consist of

Sulphuric acid	56.50		Muriate of soda	0.25
Lime	42.00		Loss	1.25

It occurs in beds in the salt-mines of Austria; in granular gypsum near Brunswick; and has sometimes been met with in the gypsum of Nottinghamshire⁷.

Sulphate of MAGNESIA is commonly found in spring water; it occurs at Hurlet near Paisley in connexion with native alum, and at various places on the continent of Europe, especially in the quicksilver mines of Idria; in the province of Andalusia in Spain; and in Bohemia. According to Kirwan, its constituent parts are sulphuric acid 29.46, magnesia 17, water of crystallization 53.54. In a cave in the Indiana territory in Kentucky, it is found perfectly crystallized in delicate white prisms, and in such abundance that the inhabitants carry it away by the wagon-load⁸.

Corneous MERCURY, or horn quicksilver, occurs in most of the quicksilver mines. Its constituent parts, according to Klaproth, are oxide of mercury 76.0, muriatic acid 16.40, sulphuric acid 7.60.

Egyptian NATRON.—This natural production is found in considerable quantity at the town of Nitria and other parts of Egypt. Klaproth analysed it, and found it to consist of

Subcarbonate of soda	32.6		Muriate of soda	15.0
Sulphate of soda	20.8		Water	31.6

⁶ Klaproth's *Analytical Essays*, vol. ii. page 129.

⁷ Jameson, vol. ii. page 248.

⁸ *American Journal of Science*, vol. i. page 49.

Native NITRE.—This production of Nature occurs in every quarter of the globe. The natural nitre of Molfetta in the kingdom of Naples consists, according to Klaproth, of

Nitrate of potash . . .	42.55		Carbonate of lime . . .	30.40
Sulphate of lime . . .	25.45		Muriate of potash and loss	1.60

Reussite occurs as an efflorescence in the country around Sedlitz, and is also found crystallized in flat six-sided prisms, and in aggregated acicular crystals. It appears to consist of

Sulphate of soda . . .	66.04		Muriate of magnesia . .	2.19
Sulphate of magnesia . .	31.35		Sulphate of lime . . .	0.42

Sassoline.—This is a natural production found on the edges of some hot springs near Sasso, a town in the territory of Florence. Its constituent parts are boracic acid 86, and sulphate of magnesia and lime 14.

RED SILVER ore.—A specimen of this mineral, found near Freiberg, was analysed by Klaproth, and found to consist of

Silver	62.0		Sulphur	11.0
Reguline antimony . . .	18.5		Concrete sulphuric acid	8.5

Sulphate of SODA, or native Glauber's salt, occurs at Eger in Bohemia, efflorescent on meadow ground; on the banks of many salt lakes in Siberia and in Egypt. It is found also on the walls of old buildings, and sometimes on those of new buildings in many parts of the world. It is found in small proportion in sea-water; but according to the analysis of the waters of the several spas at Cheltenham by Professor Brande and myself, they contain from 10 to 23.5 grains of this salt in a wine-pint of the water¹.

A specimen of native sulphate of soda from Eger was found to consist of

Sulphate of soda . . .	67.024		Muriate of soda . . .	11.000
Carbonate of soda . . .	16.333		Carbonate of lime . . .	5.643

Native SULPHURIC ACID has been mentioned already in a note at page 212. I learn from Professor Brande, that it was discovered by Baldassari in the cavities of a small volcanic hill called Zoccolino, near Sienna². Sulphuric acid is found in considerable quantity in urine, though it does not exist in the blood. The elder Rouelle showed this long ago; and Berzelius asserts that he believes it to be an essential constituent of the urine.

White vitriol, or native sulphate of ZINC, is found at Holywell in Flintshire, and in other parts of Europe. A specimen analysed by Klaproth afforded

Oxide of zinc	27.5		Sulphuric acid	22.0
Oxide of manganese . .	0.5		Water	50.0

¹ *Journal of Science*, &c. vol. iii. page 54—72.

² Brande's *Manual of Chemistry*, vol. i. page 396.

The law which governs the formation of the sulphuric salts is this:—In the neutral sulphates, the proportion of oxygen in the acid is to that of the base as 3 to 1. Thus, sulphate of soda is a compound of 1 proportional of soda 32, containing 8 of oxygen, and 1 proportional of sulphuric acid 40, containing 3 proportions = 24 of oxygen. If the composition of any of the other neutral sulphates be examined, they will be found to be formed in the same manner.

Since the above Essay was written, and indeed I may even add since the death of its author, so many and so important have been the improvements in the manufacture of sulphuric acid, that the system as accurately and minutely described by him has in many respects become exploded, and quite a new plan of burning the sulphur used in its stead. It would take too much room to detail the course of the various improvements which have been progressively adopted, and to describe their imperfections and the different methods which manufacturers have had recourse to for their remedy. I will only attempt to give a brief outline of the plan, which appears to me the best, of the utensils employed, and the methods of manipulation, without at all entering into the endless variations which occur in different works.

The chamber itself has not undergone many alterations, but the most important one is in its height. Those which have been latterly erected, only 6 feet high, are found to answer in every respect as well, and to give as good a produce, as those built upon the old plan, 12 to 16 feet high. The water-lute, too, is discontinued. The present chamber is an immense leaden room 60 to 80 feet long, 10 to 14 feet broad, and 6 to 8 feet high, the floor being formed of sheets of lead soldered together with very coarse solder (that is, containing much less tin than usual, or it would be acted on by the acid), and laid flat upon planks. The sides are hung by leaden fillets to upright pieces of timber, and are soldered carefully together; across the top other timbers are laid, to which the lead beneath is attached by small straps soldered fast to the sheets and passed over the wood.

A great advantage arising from the chamber being so much reduced in height is, that it may, instead of being placed on the ground, be supported on timbers 6 or 7 feet from the surface; by which three objects are effected. 1st, It takes no room, as the space beneath may all be employed for the purposes of the manufactory. 2nd, Any flaw in the bottom or leakage may be easily got at and repaired. 3rd, The acid may be conveyed by leaden pipes or spouts to the boilers, or to any part of the manufactory

where it is required, without the labour of putting it in bottles and carrying it.

I must now proceed to what is by far the most important part of the process,—the burning of the sulphur; and before entering upon it in its most improved form, (the result of numerous and long-continued experiments of my own, combined with all the information I have been able to obtain from others,) it will be well first to state the objections to the old system so long pursued, and even now not universally abandoned.

It has been seen that atmospheric air and vapour are essential requisites in the chamber, and that without them no sulphuric acid can be formed. The former was attained by throwing open all the doors every four hours as already described, by which immense waste of the gases was caused, amounting to one-third of the produce from a given quantity of sulphur; and the latter was produced by the heat of eight or ten fires within the house, causing an evaporation from the surface of the water: this varied with the different seasons of the year, and the house worked ill or well accordingly; besides which, the labour of charging and taking out the ashes six times during every 24 hours was great; and cleansing the house by opening the doors was not only suffocating to the operator, but filled the neighbourhood with gases destructive to vegetation and unbearably offensive to the smell.

These inconveniences and losses gave rise to many plans for burning the sulphur and nitre in separate ovens outside of the house, and conducting the gas to it by pipes.

The great cause of the total failure of many of these, and the ill operation of all, was, that sulphur burnt without sufficient access of atmospheric air, or at too great a heat, instead of becoming sulphurous gas, sublimes, and when condensed is still sulphur unaltered as to any of its chemical properties.

To prevent the sublimation of a portion greater or less of the sulphur consumed in these furnaces was found almost impracticable, from which two serious inconveniences accrued. The first is obvious,—the loss of the sulphur, which, instead of forming sulphuric acid, lies useless, adhering to the sides of the chamber: but it is worse than useless; for when the acid is put into the leaden vessel before described, to be evaporated to a proper strength, and has attained a certain degree of heat, the sulphur floating on its surface robs it of part of its oxygen, converting both the sulphur and the sulphuric acid—the one by the addition, and the other by the loss of oxygen—into sulphurous acid gas, which flies away; the sublimed sulphur thus not merely wasting itself, but also part of the acid already formed.

I will now describe the apparatus which I have found most efficacious, not only to obviate these defects, but also to produce

the greatest quantity of acid which I have ever succeeded in obtaining, viz. $2\frac{3}{4}$ lbs of concentrated sulphuric acid, sp. gr. 1.848, from 1 lb of sulphur, with its proper proportion of saltpetre.

The chamber having been already described, we will proceed with the furnace and its appendages.

The furnace is a round oven built of fire bricks about 4 or 5 feet in diameter, and the floor 2 feet from the ground; the roof is a brick arch, the crown of which rises at most 2 feet from the floor.

Iron plates are more generally used for both the floor and the top instead of a brick arch; but I find one constructed of brick so much cooler, that I give it a decided preference; as on iron the sulphur is apt to melt and run instead of burning away. The door is merely an aperture left in the front of the brick-work large enough to admit the workman's shovel, about 15 inches high and 10 inches broad. Into this a plate of sheet-iron is closely fitted, which having a handle is taken off at pleasure; in this plate a hole of 6 inches diameter is cut, before which a thin piece of tin plate is made to slide backwards and forwards, so that the precise quantity of atmospheric air required may be admitted.

Through the roof an iron pipe of 12 inches diameter is carried, and a large leaden vessel about 5 feet square and 2 feet high is placed flat on the top of the furnace; within this vessel another vessel not so high, so broad, or so long, by six inches each way, is placed bottom upwards, and soldered down to the bottom of the longer one, so that all communication between the two is effectually cut off; consequently as the pipe from the furnace passes through the bottom of the larger vessel into the small one, the fumes are confined within the latter; and the large vessel being completely filled with water, the small one is entirely immersed in that fluid, top and all four sides. From one end another smaller pipe conveys the fumes into the chamber; and as 4 inches of water are always kept on the bottom of the vessel, part of the gas is actually condensed and sulphuric acid formed, and the remainder thoroughly cooled by being passed through the water vessel, before it arrives in the chamber.

The apparatus being prepared, we will now proceed to charge the furnace. Crude sulphur is taken, coarsely ground, made into a paste with water, and as little pipe-clay or plaster of Paris added as is absolutely necessary to give it a consistency; an eighth or tenth is sufficient. This mass is with a common shovel cut up into cakes of the form of a large brick, about 20 lbs each, which are put upon a shelf on the top of the furnace to dry just enough to prevent their falling to pieces, when they are removed, as the damper they are when used the better.

Four or five of these (according to the size of your chamber or chambers) are now put into the centre of the furnace, standing on their ends; and immediately over them on a light stand is a small iron dish containing saltpetre in the proportion of one-tenth of the sulphur used, with enough sulphuric acid to decompose it. A hot iron or cinder is now applied to the cakes, which immediately ignite; and if proper care has been taken in the admission of atmospheric air, they require no further attention for many hours, but burn gently away, leaving nothing in the furnace but the pipe-clay and any impurities contained in the sulphur. The dish above is worked off on the principle of an aquafortis pot, the nitrous fumes having passed off and left sulphate of potash as a residuum. By these means the heat caused by burning the saltpetre mixed with the brimstone is avoided, and the gases as above described, being passed through water and over water, attain the chamber in the requisite state for quick condensation. As the water above is formed into sulphuric acid, it flows through a waste pipe into the chamber, and fresh water is constantly supplied by a small hole in the top of the vessel, which it will be remembered is always covered with water.

Although by these precautions the requisite supply of atmospheric air may be kept up and regulated, still the proper degree of vapour within the chamber is not insured; and accordingly most manufacturers now throw in steam from a boiler in such proportions as to supply all the water required: so that instead of commencing as formerly with water and making it stronger and stronger till of the strength required, then drawing it all off and re-commencing with water, if proper precaution be taken to throw in exactly the quantity of vapour required by the sulphur consumed, your acid may be kept at one uniform strength, and drawn off as required for the boilers or for the purposes of your manufactory.

To ascertain that your chamber is going on well, three little contrivances are requisite. 1st, A leaden shelf fixed to the outside of the house just large enough for a glass containing a hydrometer to stand upon, with a waste pipe to carry back into the chamber the fluid as it flows over. Over this glass hangs a small pipe 3 or 4 inches long, passing through the side of the chamber, in the interior of which a bit of lead should be soldered to stop the liquor as it runs down the side of the house, and cause it to pass through this pipe, falling drop by drop into the glass in which the hydrometer stands. This constantly going on, the rising or falling of the hydrometer of course denotes the increase or decrease of the strength at which the chamber is making: but this is not sufficient; as, supposing your men were to stop the steam from entering, and neglect the sulphur furnace, no decrease of strength would take

place, but there would be no increase of quantity. To ascertain the latter, a simple plan suffices. Let an open-topped leaden cistern 6 inches square be attached to the bottom of the chamber with a free communication, and in this place a tube open at both ends, but at one decreasing almost to a point; the tube should be graduated in eighths of inches: by dipping the small end to the bottom of the cistern, and when filled applying your thumb closely to the top, and then withdrawing the tube from the vessel, you see at once the exact depth, and what it has increased in quantity since you last tried it. You may thus know its strength and quantity at any time, as the former merely requires looking at, and the latter only taking a tube in your hand; so that no alterations in the working of your chamber, however slight, can take place without being instantly perceived.

The third simple but very useful instrument is called the subliming rod. It is merely a round bar of lead passed through a hole in the side of the chamber, so that about two feet are within the chamber and one without for a handle. It is kept steady by being passed through a thick piece of lead attached to the side, which it exactly fits. By withdrawing this rod at any time, the way in which the chamber is working will be evident; as if there is the slightest sublimation, the flowers of sulphur will be visible upon it; but if it is wet, and the acid hanging upon it in drops, we may conclude that all is going on well.

The next thing to attend to is the method of getting rid of the incondensable gases without waste, as it will be recollected we have no doors as formerly to throw open and to clear out altogether.

A vessel is carried outside the whole length of the house, or still better if all round the house, 18 inches broad and 6 inches deep: another vessel not quite so broad, but 18 inches high, is turned bottom upwards and placed in the small one, which is filled with water to the depth of 3 inches. This is called a water-lute, and is the principle on which all the chambers were formerly built; it will easily be seen that the water effectually prevents any escape of gas. One end of the upper vessel is connected by a pipe to that part of the top of the chamber which is furthest from the furnace, and to the other end of this water-lute is a waste pipe connected with a high brick chimney, generally the one belonging to your steam boiler.

In this latter pipe is fixed a valve to regulate the draught and prevent the escape of sulphurous gas, which would happen if it were too quick. Thus the whole apparatus is kept in motion; the suction of this chimney (if I may be allowed rather an unphilosophical mode of expression) causes a draught through the water-lute and the chamber all the way back to the furnace:

another and still greater cause of draught is that which the vacuum in the chamber itself, caused by the condensation of the gases within it, produces.

This draught once existing, atmospheric air constantly rushes into the furnace; the gases then pass with it through the cooling cisterns into the chamber; there nine-tenths are condensed; the remainder before they can escape have to travel through perhaps 300 feet of water-lute, condensing as they go; and by the time they arrive at the chimney it may be presumed that little is left but the azote and other useless incondensable gases. The acid formed in the water-lute flows into the house through waste pipes placed there for the purpose.

Thus I have described briefly, but I fear obscurely, what I consider the best system now in use for making sulphuric acid of the strength it is in the chamber. A pipe from the bottom conveys it either to those parts of the manufactory where it is consumed in this weak state for bleaching powder, muriatic acid, &c. or leads it into the leaden boiler, where it is evaporated, as already described by Mr. Parkes, to as high a strength as lead is capable of allowing. It is then finished in open-necked glass retorts, on sand heats, with a separate fire under each. By putting a few strips of platinum into every retort, the jerks and spoutings of the acid, which frequently break the glass, are prevented; and by the simple contrivance of a sheet-iron cap over the top of each, the danger arising from draughts of cold air is avoided; and a manufacturer with whom I am acquainted lessened his yearly breakages nearly three-fourths by this one addition. The acid lies in the retorts till a little cooled, and each retort is then lifted out, and the contents emptied into a carboy previously warmed to receive them. But by some makers a much better system has been introduced, by which the extreme danger of this frightful task is avoided,—a task in the execution of which, men have been so severely wounded by the bursting of the retorts containing the hot acid, as to be confined to their beds for many months with inveterate scalds. This improvement is to extract the acid from the retort standing in its sand heat by means of a syphon with a cock at one end. By a little management in not quite emptying each retort, but leaving in about half an inch of acid, the syphon never empties, but may be carried round to fifty retorts without requiring refilling.

All the monstrous expense of coals, breakage of glasses, labour, and personal danger, is now avoided in large manufactories by the use of platinum vessels instead of glass. The only objection is the enormous first cost. Mr. Pariss, of Battersea, has lately erected one, capable of concentrating 20 carboys per diem, which cost him 1200 guineas: it is perhaps the most complete one

that has been made; and allowing amply for wear, tear, and interest of money upon it, he finds that it is a saving to him of several hundreds per annum. Mr. Parkes found a leaden cover to answer equally well with one of platinum; and if this alteration were adopted, I believe that half the sum I have specified would suffice to erect one capable of doing as much work and as well.

A platinum vessel also gives you the opportunity of throwing back into your chamber the gases which arise from the boiling liquor, and the sulphuric acid which distills over during the latter part of the operation; by which, not merely a saving is effected, but the intolerable nuisance which those gases are to the surrounding neighbourhood is entirely avoided. And I think it is a general rule which admits but few exceptions, that in proportion to the smells and annoyance arising out of any chemical manufactory, are the waste, mismanagement and inattention within its walls.

ESSAY VIII.

ON CITRIC ACID.

The Median fields rich citron fruits produce,
 Though harsh the taste, and clammy be the juice ;
 Blest antidote ! which, when in evil hour
 The stepdame mixes herbs of poisonous power,
 And crowns the bowl with many a muttered spell,
 Will from the veins the direful draught expell.
 Large is the trunk, and laurel-like its frame,
 And 'twere a laurel were its scent the same ;
 Its lasting leaf each roaring blast defies,
 Tenacious of the stem, its flowrets rise :
 Hence a more wholesome breath the Medes receive,
 And of their Sires the lab'ring lungs relieve.

WARTON'S Translation of VIRGIL'S *Georgics*.

THERE is a peculiar acid in the juice of lemons, citrons, limes, and a variety of other fruits, different in some of its properties from all others, and known to chemists by the name of the CITRIC ACID.

It does not appear that the ancients set any value on the juice of these fruits, except as an antidote against poison, or that they ever employed it in considerable quantities for any purpose whatever ; though from some lines in Virgil's *Georgics*, part of which I have taken as a motto for this Essay, it is evident they had a high opinion of its virtues in counteracting the effects of some deleterious drugs or vegetables.

As lemon juice can be procured with advantage only at one season of the year, and is apt, whatever care may have been taken with it, to spoil in keeping, on account of the sugar, the water, the extractive matter, and the mucilage which it contains, all of which tend to throw it into a state of fermentation, it became an object to chemists to divest it of these imperfections, and thus to procure the real acid of the fruit in a state of perfect purity.

Scheele and other practical men attempted to separate these matters by means of alcohol : but this intermedium effects the desired purpose very imperfectly ; for though it will divide the mucilage, it has not the power of separating the extractive matter or the sugar.

In the year 1774, M. Georgius, a Swedish chemist, published in the Stockholm Memoirs a process for separating the mucilage and concentrating the acid, by keeping the lemon juice for some

CHEMICAL ESSAYS.

PLATE 7



A. *Trunks of glass*
B. *Wooden Vat*
C. *Crystall. Glass*
D. *Crystall. Glass*

E. *Leadens bottles*
F. *Trunks of glass*
G. *Crystall. Glass*
H. *Crystall. Glass*
I. *Crystall. Glass*
J. *Crystall. Glass*
K. *Crystall. Glass*

Chemical and Manufacturing

at Prince St.

in Dover street.



time in a cool place in inverted bottles, and then exposing it to cold at some few degrees below the freezing point; and in this way separating the water, which, with the remaining mucilage, freezes; and this frozen portion is directed to be repeatedly removed. The liquor is then submitted again and again to the action of the frost, till it is reduced to one-eighth of its original quantity. By this management none of the acid is lost; and when it is thus concentrated, it may be kept for many years without sustaining any injury.

On this process, to which there is little objection except the time required for its completion, and that it can be effected only at one season of the year, it is necessary to remark, that care should be taken not to expose the juice to a degree of cold too intense, lest part of the acid also be congealed with the aqueous portion, and thus defeat the intention. Whereas, if it be submitted to the action of the frost when the thermometer is between 28° and 32° , and the ice be carefully removed as it forms, the juice may be reduced to an eighth part of its former bulk, and consequently increased in strength, because the remaining eighth will really be equal in its saturating power to the whole of the original acid.

This process will answer very well for domestic purposes, and the concentrated acid may be long preserved by mixing it with 7 or 8 times its weight of refined sugar in powder: but it affords no assistance in furnishing the concrete citric acid; for, after the juice has been thus condensed, still enough of the extractive matter will remain in it to prevent the crystallization of the acid.

After the publication of this paper by Georgius, a Mons. Du Buisson of Paris announced another method of concentrating and preserving lemon juice. This consisted in reducing its quantity by the action of a gradual heat kept up for a considerable time, which has the effect of thickening the mucilaginous matter, and occasioning its separation in a glutinous mass on the surface of the liquor. When this is removed, the remaining juice may be preserved a long time unaltered.

Both these proposals may be viewed as approximations towards the development of the true method of purification, which was reserved for that enterprising and renowned Swedish chemist, who has immortalized his name by discoveries of far greater importance than that which is now under consideration.

The ingenious Scheele was the first who exhibited this acid in a solid form; and to accomplish this end, he adopted merely the same method which he had employed long before in the purification and crystallization of the tartaric acid.

It consists in separating the real acid by means of carbonate of lime, and then decomposing the citrate of lime by the interme-

dium of diluted sulphuric acid;—a process which has been universally adopted throughout Europe; there being no other means yet discovered of putting this acid into a crystalline form.

Having myself had some experience in this process by frequently superintending its progress, and more than once to the extent of several hogsheads of juice in one operation, I shall now, with some confidence in their correctness, proceed to give what appear to me to be the best directions for obtaining a successful and economical result.

The juice, which is imported in pipes and hogsheads, should be drawn off into a large open vessel;—a square vat made of fir is very proper for the purpose. In this vessel the juice is to be saturated with lime, by the gradual addition of clean soft chalk, or whiting. Care must be taken to note down the quantity of carbonate of lime employed, which should be added till it occasions no further effervescence, and until the liquor shows no signs of acidity on test paper.

I have said that the chalk should be added very gradually, because otherwise the effervescence, by the disengagement of carbonic acid, will be so considerable as to occasion a great part of the contents of the vat to flow over and be lost.

If the cask containing the juice be rolled near to the vat, a small copper hand-pump may be put in at the bung-hole; and while one man is slowly pumping it into the vat, another should not cease to agitate the whiting; and whenever there is any danger of the mixture rising too high in the vessel, the operators will have only to rest a moment, and all will be safe. In this way the saturation will be complete, and it will be done in the least possible time.

In this process all the real acid of the lemon juice is absorbed by the calcareous earth; and when the combination is completely formed, the citrate of lime, which is an insoluble salt, precipitates to the bottom of the vessel. When the whole of this has fallen, the supernatant liquor, which will be nearly tasteless, will be found to contain nothing besides the mucilage, except a portion of the essential oil of the rind of the fruit, some extractive and saccharine matter, and a little malic acid. This supernatant liquor is therefore to be drawn off, and the precipitate preserved for use.

If it be desirable for any part or the whole of the *malic* acid to be saved, it may readily be distinguished from the citric by the following properties: The malic acid does not crystallize; it precipitates silver, mercury, and lead, from their solutions in nitric acid, while citric acid has no such effect; and it forms a *soluble* salt when combined with lime.

It is usual, as I have seen in some of these establishments, to have plugs in the side of the vat, and at different heights, for the purpose of drawing off the supernatant liquor; but a syphon with a stop-cock is much more convenient; for with it the liquor may at any time be drawn off perfectly close, and the danger from a plug flying out be avoided.

When the supernatant liquor is removed by a syphon or otherwise, the precipitate, or citrate of lime, is to be passed through a sieve, and then frequently washed with warm water, until all the remaining mucilage and other soluble impurities be entirely washed off; which will be known, when the whole has remained at rest for some time, by the water coming off clear and tasteless.

The precipitate, having been thus well washed, let it be treated with diluted sulphuric acid in the following manner:—For every ten pounds of chalk or whiting, which has been employed in the process, it is necessary to take the quantity of nine pounds and a half of sulphuric acid of the specific gravity of 1.84 or 1.845, which is to be diluted with about seven gallons, or fifty-six pounds of water.

The diluted sulphuric acid is to be poured gradually upon the citrate of lime, and the whole mixture well stirred, for a considerable time, with a strong wooden spatula, that there may be no chance of any of the citrate remaining unbroken, and consequently unacted upon by the stronger acid.

In conducting this part of the process, I have noticed an appearance worth mentioning, which is this:—It being necessary to stir up the mass very frequently during the gradual addition of the sulphuric acid, I have observed that whenever the citrate of lime became nearly all decomposed, and the earth mostly saturated with sulphuric acid, the sulphate of lime precipitates quicker and quicker after every addition of this acid, and that the supernatant liquor considerably increases in quantity. The latter circumstance is occasioned by the increased density of the precipitate; and both appearances should always be looked for, as they afford a good criterion for judging of the progress of the operation.

It is, however, proper to remark, that it would not be prudent for the operator to rely solely on these appearances; for, if he is to ensure the best possible management of the process, he must have recourse to the agency of chemical tests, as they will afford the only sure criterion by which the real state of the saturation of the lime can be known.

In many chemical operations, preparations of barytes, or a simple solution of this earth in water, are employed to detect the presence of sulphuric acid. But as citrate of barytes would immediately precipitate on the addition of barytic water to a solu-

tion of citric acid, this reagent cannot be conveniently employed to show when the exact quantity of sulphuric acid has been used.

Whenever the saturation of the citrate of lime is nearly completed, and the operator is fearful of supersaturating it, all that is necessary is to take out a little of the clear liquor, after the precipitate has subsided, to filtrate this liquor through paper, and then treat it with a few drops of acetate of lead. In this instance a citrate of lead will be formed, and precipitate, which precipitate will be immediately redissolved on the addition of a little of the nitric acid. On the contrary, should too much sulphuric acid have been used, there will be a mixed precipitate of citrate of lead and sulphate of lead; and the latter of these salts not being soluble in nitric acid, leads to the detection of an excess of the decomposing acid.

But to return to the process. The consequence of this affusion of the citrate of lime with sulphuric acid is this,—the sulphuric acid having a more powerful affinity with the lime, it combines with that earth immediately as it is poured upon the washed pulp of citrate of lime, and by this action it displaces the citric acid, which will then be found in the supernatant fluid.

The insoluble part of the mixture is now *sulphate* of lime; and when sufficient time has been allowed for the whole of this to precipitate, the fluid, which is the pure citric acid in a state of solution, may be drawn off for use.

In order, however, to procure the whole of the citric acid, more water must be poured on the sulphate of lime, and this washing repeated time after time, until the last portion of water comes off clear and tasteless.

In opposition to some directions which I have seen, I would advise that *cold* water be employed for these washings, as it will separate the fluid citric acid from the precipitate, equally well with hot water, and will dissolve less of the sulphate of lime, which is a substance very unfavourable to the process of crystallization.

The whole of these washings are to be put together, and the mixed liquor is afterwards to be concentrated by evaporation, which is performed in leaden vessels cased with wood, with a coil of pipe covering the bottom, connected at one end with your steam boiler, and the other having a small cock to let off the condensed water. By these means a great saving of fuel is effected, and no danger need be apprehended of decomposing the acid by too great a heat, which was frequently the case when it was boiled down over a naked fire. When these larger boilers have brought the liquor into about one-eighth of its bulk, their contents are transferred into one of a smaller size, and they are again filled with weak acid washed from the sulphate of lime.

In this last vessel the liquor is to be further evaporated until it acquire the consistence of very thin molasses, and then it should be watched with the greatest attention for the appearance of the pellicle, which may now be expected to rise on the surface. This pellicle will first show itself in small detached spots, and these, by degrees, will increase in size and number until the whole of the liquor is nearly covered with them. The concentrated citric acid should then be immediately taken out of the bath, and laid aside in other shallow leaden vessels to cool and crystallize.

It is of the utmost consequence to attend to this circumstance; for so much of the fluid is evaporated before the pellicle appears, that, if it were to remain in the concentrating vessel half an hour longer, the whole might be carbonized and reduced to a useless and inert mass.

When removed, it should remain undisturbed for three or four days, that the largest possible quantity of crystals may be obtained from the liquor. After this time has elapsed, the mother-water may be drained from the crystals; because, after that period, it will be in vain to expect a further increase without a further abstraction of water by a fresh evaporation.

It is likewise proper to remark that, however carefully the process may have been conducted, the whole of the calcareous earth will not precipitate while the supernatant liquor is loaded with the citric acid; for we know that this is capable of holding the citrate of lime in solution. Dizé having dissolved 100 parts of crystallized citric acid in pure water at 212° , found that the solution would take up 50 parts of calcareous citrate¹. Hence some nicety is required in separating the lime, without adding an unnecessary and injurious quantity of sulphuric acid. It will therefore be advisable, as the acid becomes concentrated, to add occasionally a small portion of diluted sulphuric acid, which will arrest the lime, and precipitate it. To this end, the steaming should every now and then be discontinued for some hours, to allow time for the sulphate of lime to separate, which otherwise would prevent the crystallization of the pure citric acid; for Crell has shown, that a very small quantity of calcareous earth will have this effect. A single drop of sulphuric acid will, however, be a sufficient test, at any time, to show whether the concentrated citric acid holds any citrate of lime in solution. Moreover, a small excess of sulphuric acid is not injurious, but will rather favour the crystallization of the citric acid.

In opposition to what Crell has observed respecting the crystallization of the citric acid being prevented by the presence of

¹ *Journ. de Phys.* 1794, tom. ii. page 231.

lime, Westrumb says that most of the citric acid, even when crystallized, contains a considerable quantity of lime. However, where this is suspected, it may quickly be known by dissolving some of the crystals in water, and, when the solution has been saturated with ammonia, by treating it with an oxalate of that alkali, which, if there be lime, will immediately separate it in a palpable form.

When the product is laid by for crystallization, it will not be necessary to attend much to the temperature of the room, as I have discovered by experience that the crystals shoot equally well in a warm as in a cold situation.

The crystals thus produced will sometimes, though not generally, be needle-formed; though it has been repeatedly said by the writers on citric acid, that the crystals produced by the first evaporation are *always* needle-formed; but I am inclined to think that this will never be the case if the citrate of lime has been properly freed from the mucilage, and the solution of citric acid not evaporated beyond the due point of concentration, before it be laid aside for crystallization. Indeed, by proper management, I know that perfectly formed rhomboidal crystals may always be procured from the liquor of the *first* boiling. As the process is usually conducted, these first crystals will be nearly as dark as the brownest sugar. Indeed, every writer on citric acid, whom I have consulted, tells us, that the first crystals will be either dark brown, or black; but I am confident, if the article has not been burnt during the evaporation, that this must be owing to the mucilage not having been sufficiently washed out of the citrate of lime before it is treated with the sulphuric acid; for I have more than once seen crystals of the first crop of a very bright light brown, and even distinct in their form; and such, I conceive, they always will be when the proper precautions have been taken.

Although the crystals of citric acid in any of these states may very well answer most of the purposes to which they are applied by the calico-printer, it is sometimes desirable to have them quite pure; and by dissolving them in pure water, boiling them up with a small quantity of animal charcoal, by means of a pipe blowing steam into your dissolving tub, and then passing the liquor through a flannel filter in a regular filtering box, all colour will be destroyed; and when you have evaporated and crystallized as before, very white and beautiful solid crystals of citric acid will be produced; for though the first product may be in needle-shaped crystals, the acid when further purified will always appear in rhomboidal prisms: and if this second crystallization should not in every instance bring them to the requisite form and degree of whiteness, another boiling and charcoal filter-

ing may always be depended upon, unless some gross neglect occurs during the operation, and the acid is carbonized by being evaporated too far, or discoloured by dirt falling into it.

There is another point respecting the conducting of this business which deserves our notice, and that is the management of the mother-waters. In the manufacture of every kind of salt, or crystalline acid, the profit very much depends upon the economy which is observed in reducing the mother-waters to a solid and a marketable form. But in this article, the high value of the crystals, and the peculiar difficulties attendant on the reduction of these residuary liquors, render this part of the subject important to those who operate upon a large scale.

Whenever this acid is first boiled to a sufficient strength for crystallization, the small excess of sulphuric acid carbonizes a portion either of the acid or the mucilage; and therefore, when several parcels of lemon-juice have been concentrated, there will at last be a considerable quantity of very black uncrystallizable mother-liquor.

This liquid residuum has given much trouble to some operators, and it has often been thrown away as useless. By the following management, however, the whole of the citric acid which it contains may be turned to a good account, and produce fair and clean crystals. The process which I would recommend is as follows:

Whatever the quantity of mother-liquor may be, let it be diluted with ten or twelve times its measure of pure water, and the water intimately mixed with it. Then add carbonate of lime to it, by degrees, until it is completely saturated, and proceed with it in all respects as directed at page 250, as if it were fresh lemon-juice.

Here it will be necessary to wash the product of citrate of lime with several successive portions of water; and, if this be attended to, the crop of crystals which it will yield will be as fine as any before obtained.

On referring to the notes which I made in the year 1810, while operating on some large parcels of lime juice, I find the following entry, which is descriptive of the whole process, and is given in the hope that it may furnish some useful hints to those who have had less practical experience, and enable them to avoid some errors into which I had fallen before I had that knowledge of the process which I have since acquired.

Three casks of lime juice, which measured together 270 gallons, were drawn off into a large wooden vessel; and to this were added 118lbs. of clean carbonate of lime, which completely saturated it. When the citrate of lime had precipitated, the

supernatant liquor was taken away and reserved for another purpose¹. The precipitate was then carefully washed with hot water from the worm-tub of the laboratory still, and this was drawn off the next morning. The precipitate was afterwards washed several times with cold water; in all seven times, the first washing only being with *hot* water. The water which was drawn off even at the third washing was considerably coloured.

While the citrate of lime was precipitating after the last washing, (and I allowed it due time to subside, in order to separate as much as possible of the water which rested on its surface,) I drew off into another vessel the contents of five pipes more of lime juice, which in the whole measured 450 gallons. Lime juice is generally stronger than the juice of lemons, and when it is of the full standard strength it will require half a pound of chalk to every gallon of the juice. Hence it appeared, when too late, that a good price had been paid for a very inferior article; —an inferiority which I imagined was not occasioned by adulteration, but proceeded merely from the natural effects of age. And here it is important to remark, that ordinary juice not only takes less lime, but that sometimes even a considerable portion of what is used does not remain in the vat, but is drawn off with the malic and acetic acids; the malate and the acetate of lime being both soluble salts. Hence the necessity of always employing a chemical test to determine the quantity of sulphuric acid required for the subsequent operation, lest a dependence on the quantity of carbonate of lime used, might mislead. The five pipes of lime juice above mentioned required 149 pounds of carbonate of lime for its complete saturation.

The precipitate now obtained was treated and washed with the same attention and care as the former, to separate the whole of the malate and acetate of lime, the extractive matter, and the mucilage. Both the precipitates were then removed to a leaden cistern, and 500 pounds of soft water were poured over them, which enabled us very thoroughly to mix the whole.

Two hundred and forty pounds of sulphuric acid of the specific gravity of 1.845 were now diluted with 256 pounds, or 32 gallons wine measure, of soft water, and this diluted sulphuric acid was immediately, whilst hot from the mutual action of the two fluids upon each other, gradually poured in successive portions

¹ When I reserved this liquor, it was my intention to have separated most of the water, either by evaporation or freezing, and then to have treated the malic acid and the mucilage which would remain with nitric acid, with the view of obtaining oxalic acid, which I thought would be a means of producing some profit, and thus economizing the first process. But I never pursued this object.

into the leaden cistern upon the mixture of citrate of lime and water.

While this was doing, two of the workmen never ceased stirring up the whole from the bottom of the cistern, with large and strong wooden spatulas, the more effectually to prevent any part of the citrate of lime from escaping the action of the sulphuric acid.

Notwithstanding this, I perceived that the precipitate conglomerated very much on every addition of the sulphuric acid;—a circumstance which was occasioned, as I afterwards discovered, by using this acid in too concentrated a state. There is besides another evil attending this; for as sulphuric acid, fully concentrated, will convert the citric into acetic acid, there will always be a danger of lessening the quantity of the produce, when the sulphuric acid is not sufficiently diluted before it is employed. Indeed, from the last operations which I superintended, I am led to believe that it cannot be economical to use this acid in a higher state of concentration than one part of strong sulphuric acid to six parts of water.

The whole quantities used were as follow:—Lime juice 720 gallons; carbonate of lime 267 pounds; sulphuric acid 240 pounds; water, mixed with the sulphuric acid, besides the quantity which was before in the citrate of lime, 756 pounds.

It may here be observed, that if the citrate be treated with oil of vitriol *immediately* after it has been washed, as is frequently the case, a dilution of three parts of water to one part of sulphuric acid may be sufficient, as there will be much water in a state of mixture with the citrate of lime.

Several other parcels of citrate of lime were afterwards treated with sulphuric acid properly diluted, and the several inconveniences which I have adverted to were avoided; but it is not in my power to furnish the amount of the crystals that were produced from any of these parcels, as I disposed of my share of the whole of the citric acid in a state of solution, and the task of concentrating it for crystallization fell into other hands.

From other experiments, however, I have reason to conclude that 20 gallons of good lemon juice will generally give 18 pounds of dry citrate of lime, and that if the whole process be well conducted, these 18 pounds of citrate of lime will furnish 10 pounds of good white crystals of citric acid. A well known and highly respectable chemical writer has stated, that “the quantity of solid citric acid in a gallon of lime juice, varies from 14 to 18 ounces.” I confess, however, that I have not been able to procure this proportion from any of the parcels on which I have operated; but there is reason to believe that his experiments were made with lime juice recently expressed from the fruit.

Fourcroy in his "*General System of Chemical Knowledge*," vol. vii. pages 277 and 287, and in the Lectures which he delivered at Paris, recommended to his fellow-citizens to send proper persons over to their American possessions to collect the vast quantities of limes and lemons which are annually lost there; to saturate the expressed juice with chalk; and to send the washed and dried precipitate, closely packed in barrels, to France, where it might be decomposed, and the citric acid obtained pure. Whether any of the Parisians ever embraced this proposal I have not been able to learn; but I know that some persons have gone from England to different parts of Italy for this purpose, and that considerable quantities of the citrate of lime have been imported from thence into Great Britain.

Having been introduced to a person, who some years ago formed an establishment of this sort in the island of Sicily, I have learned several important circumstances relating to this business, which have never yet been given to the public. I have also been favoured with the perusal of a great part of the correspondence which passed on the occasion; and having obtained leave to print the whole, or any part of these letters, I shall subjoin such extracts as I conceive will be interesting to those who may be desirous of acquiring more information on the subject.

In the first letter, which is dated Messina the 6th September, 1808, this intelligent correspondent says, "The time of pressing is generally in the latter end of the month of November or December, for until that period the lemons yield little or no juice."

"The country round Messina consists of mountains of immense height, rising one above another, and thickly covered to the very tops with fruit-trees, chiefly olives and lemons, which render this place the very best in the world for procuring lemon juice."

"The quay surpasses most others, extending for a mile and a half, close to the edge of which ships lie in 20 fathom water. Formerly a range of superb houses, perfectly uniform, extended the whole length of this marino, or quay; but ever since the earthquake these magnificent mansions lie in ruins."

"As soon as the country people press the juice, they bring it in here for sale. The buyers do not afford it warehouse-room, but roll it into the street, where it remains exposed to the weather and to the heat of the sun, till an opportunity offers for shipping it. It is therefore not surprising that so much is imported that is musty and perished, and that the English merchants often find it so bad on its arrival in England as to create a difficulty in procuring for it even the amount of the import duty."

In one of his letters he remarks, that in the autumn 200 lemons are generally required to furnish one gallon of juice; and that on this account, there are presses in the island which are so

constructed that they will squeeze many thousands of lemons at once.

April 15th, 1809. "I have hitherto found no difficulty in saturating the chalk in any quantity; but the drying is extremely tedious and difficult; it requires very hot and dry weather, which we have had little or none of as yet. I have had parcels lie upwards of a fortnight before they became perfectly dry. When spread out for this purpose, it occupies a vast deal of room, and when the drying-places are all full, I am obliged to stand still, although I have procured the use of a vast terrace belonging to a convent not far distant."

"The cistern in which I work is capable of containing 12 pipes; but notwithstanding the large size of the apparatus, the effervescence occasions me much trouble; and this I attribute to the chalk being sifted to so fine a powder."

"Neither the monks nor any of the inhabitants seem to have the slightest curiosity to know what the article is, although, until it is dry, it continually occasions a most agreeable odour."

June 22, 1810. "I find as much difference in lemon juice as in wine, and both have more or less body, according to the particular soil on which the fruit grows. When fresh squeezed, all seems equally sharp and good. The hot weather, however, is the test, and there is much of the juice we buy which will not bear it; it often changes *very quickly*, and a mawkish vinegar-sort of taste alone remains. Though the early juice resists the heat the best, I can positively assert that, with the utmost care, there is no *certainty* of preserving its native sharpness in the hot months, but by the addition of lime, or some other similar agent."

The following is a tabular view of the quantities of citrate of lime sent from this establishment to England at each shipment; with the respective quantities of juice and carbonate of lime that were employed in its formation.

Times of Shipment.	Avoirdupois Pounds of Citrate.	Pounds of Chalk employed.	Gallons of Juice employed.	Ounces avoirdupois of Citrate from every Pound of Chalk.		Ounces avoirdupois of Citrate from every Gallon of Juice.	
				Oz.	Drms.	Oz.	Drms.
1809, May 8	3329	2386	4773	22	5 $\frac{1}{8}$	11	2 $\frac{1}{2}$
25	2047	1318	2638	24	13 $\frac{1}{2}$	12	6 $\frac{5}{8}$
July 1	6426	3981	8029	25	13 $\frac{1}{4}$	12	12 $\frac{7}{8}$
15	3750	2281	4885	26	14	12	4 $\frac{1}{2}$
1810, June 5	4987	3230	6485	24	11 $\frac{1}{4}$	12	4 $\frac{1}{4}$
22	8022	5314	10917	24	2	11	12
July 15	7181	5827	13117	19	11 $\frac{1}{2}$	8	4 $\frac{1}{2}$
Aug. 22	6798	4930	11098	22	1	9	6 $\frac{1}{4}$
	7362	5800	13022	20	4 $\frac{7}{8}$	9	0 $\frac{1}{2}$
	49902	35017	74964				
Average Produce				22	12 $\frac{3}{4}$	10	10 $\frac{3}{8}$

On account of the great disproportion which there is in the amount of the different parcels of citrate of lime, produced from their respective parcels of lemon juice, less reliance is to be placed on this table as a perfect document of general reference, than otherwise might be: but as this must have been owing to the operator not being aware of the great difference which there is in the quality of the juice offered for sale, I have taken the pains of throwing the whole of the results into this tabular form, that they may appear at one view, and be a warning to future speculators how they make contracts for lemon juice without submitting the several parcels to previous chemical examination.

As to the disproportion in the quantities of citrate of lime produced from the respective parcels of chalk, and which vary from 20 to nearly 27 ounces for each pound of the earth employed, this must have arisen from his having taken the same quantity of carbonate of lime per gallon for every parcel of lemon juice, as he intimates in one of his letters, than which nothing could have been more improper; as the produce of citrate would sometimes not only be much less than it ought to have been, but, from the earth not being saturated, the article would be of very inferior value.

Considering the difficulties which I have already stated, I am inclined to think that by purchasing lemon juice in London or Liverpool, at favourable opportunities, citrate of lime might be made in England nearly as cheap as it could be imported from Sicily, to say nothing of the inconveniences and disadvantages which must inevitably attend its formation in a distant country. The reader, however, will be able to form his own opinion from the facts which I have detailed.

I am desirous of observing that the juice of several other fruits, besides those of limes and lemons, will furnish the citric acid, either alone or mixed with other vegetable acids. Thus, the cranberry, the *vaccinium oxycoccus* of Linnæus; the red whortleberry, *vaccinium vitis idæa*; the birds cherry, *prunus padus*, a fruit that is often infused in wine or brandy, to give it an agreeable flavour; the berry of the nightshade, *solanum dulcamara*; and the hep, or fruit of the wild briar, *cynosbatus* vel *rosa canina*, yield chiefly the citric acid¹: while in the red gooseberry, *ribes grossularia*; in the garden currant, *ribes rubrum*; the bilberry, *vaccinium myrtillus*²; the hawthorn, *cratægus aria*³; the black

¹ Westrumb has shown that the juice of the common cherry contains scarcely any other acid than the citric.

² The juice of this berry has been employed to stain paper, or linen, purple. In autumn the moor-game chiefly live upon the product of this shrub.

³ The wood of the *cratægus aria*, on account of its great toughness, is much used for making wheels and axletrees; it is also so hard and smooth a wood that it is highly esteemed for making the handles of sundry tools used by carpenters and others.

cherry, *prunus cerasus*; the wood strawberry, *fragaria vesca*; the knout or cloudberry, *rubus chamæmorus*; and in the raspberry, *rubus idæus*,—it is mixed with nearly an equal proportion of malic acid. From all of these the citric acid may however be separated by means of carbonate of lime, if ever a scarcity of limes and lemons should occur.

Simon Pauli has published the method of making a concrete salt from the juice of the barberry; and directions for making barberry-punch of a beautiful red colour are given by Weigleb⁴.

It may also be worth mentioning, that sometimes there is a large quantity of damaged tamarinds in the market, which might be bought cheap enough for the use of calico-printers, and which would afford their citric acid to calcareous earth, in the same way as the common lemon juice. Vauquelin, who has made direct experiments upon the tamarind, has shown that one pound of the pulp contains one ounce and a half of solid citric acid⁵.

In adverting to the PROPERTIES of the citric acid, its chemical affinities first present themselves to our notice. These, as determined by Bergman, and by Mons. de Breney of the Academy of Sciences at Dijon, are in the following order:

Barytes,	Soda,	Oxides of	Manganese,	Copper,	Antimony,
Lime,	Strontites,		Iron,	Tellurium,	Silver,
Magnesia,	Ammonia.		Lead,	Arsenic,	Gold,
Potash,			Cobalt,	Mercury,	Platinum.

It is observable, however, that Vauquelin places Magnesia after Potash, Soda, and Strontites⁶.

When the citric acid is pure and concentrated, it crystallizes in rhomboidal prisms, the sides of which are inclined towards each other at angles of 60 or 120 degrees, terminated at both ends by summits with four faces, which intercept and include the solid angles⁷. Its taste when crystallized is strongly acid and pungent; but when dissolved in water, mild and agreeable. It reddens litmus and other blue vegetable colours. The crystals are soluble in their own weight of water, or according to Vauquelin 75 lbs. of water at the temperature of 60° are capable of dissolving 100 pounds of the crystals: boiling water will dissolve twice its weight of them. When the crystals are heated gra-

⁴ Hobson's *Translation of Weigleb's Chemistry*, 4to, London, 1789, page 178.

⁵ Vauquelin's Memoir on the Analysis of the Tamarind will be found in the *Annales de Chimie*, tom. v. page 92.

⁶ See Fourcroy, vol. vii. page 287.

⁷ Dizé, Nicholson's *Journal*, 4to, vol. ii. page 44.

dually over a fire, the acid becomes dissolved in its own water of crystallization. It undergoes spontaneous decomposition, if long kept in solution, even in close vessels; though lime juice may be preserved good for a long time in glass bottles, if covered with a thin stratum of oil. By concentrated sulphuric acid it is converted to acetic acid; and lastly, the alkaline citrates are decomposed by barytic water.

The crystals of citric acid according to Berzelius consist of 100 acid + 26.5 water, or 100 parts of the pure crystals are composed of 79 acid and 21 water. The same chemist determined¹ that the constituents of the acid are in 100 parts: oxygen 54.831, hydrogen 3.800, carbon 41.369; or 4 proportionals of oxygen 32, 2 of hydrogen 2, 4 of carbon 24, making its equivalent number 58.

The citric was formerly supposed to be identical with the tartaric acid; but they differ in one remarkable particular, viz. that the citric acid does not decompose muriate of potash. It is also readily distinguished from the oxalic acid by its incapacity of decomposing sulphate of lime.

Acetate of lead is decomposed by citric acid, and the citrate of lead that is formed is precipitated in a white powder. The nitrate and acetate of mercury are also decomposed by it; and it imparts a green tinge to the solutions of acetate and sulphate of iron.

The SALTS which have been formed by means of the citric acid, being more the objects of curiosity than of utility, a very brief account of them will be sufficient. They are as follow:

Citrate of AMMONIA.—This salt is formed by dissolving carbonate of ammonia in citric acid. To produce it in crystals, the solution must be evaporated to a thick syrup. Its crystals are elongated prisms, composed, according to Vauquelin, of 62 acid and 38 ammonia². They are very soluble in water.

Citrate of BARYTES is prepared by adding a solution of pure barytes to a solution of citric acid. The salt forms itself into a kind of bush of a silvery whiteness, very brilliant and beautiful; though sometimes it appears in more distinct acicular crystals. It is composed of 50 parts by weight of crystallized acid, and 50 of barytes.

Citrate of BISMUTH was formed by Vauquelin, and found to be an insoluble white powder.

Citrate of COBALT.—This compound is formed by the union of

¹ *Annals of Philosophy*, vol. v. page 93.

² Fourcroy's *General System*, vol. vii. page 283.

the oxide of cobalt with citric acid. The product is a soluble salt, whose properties are unknown.

Citrate of COPPER.—Citric acid acts very feebly on metallic copper; but this salt may be formed by boiling the oxide of copper in a solution of citric acid. The concentrated solution, on cooling, yields light green crystals.

Citrate of GLUCINA.—This salt may be readily formed, but it does not seem that its properties were examined by Vauquelin when he was engaged in investigating the nature of the other citric salts.

Citrate of IRON has been formed by Vauquelin. When he added iron to citric acid, the effervescence continued four days; the solution was of a brown colour; and by spontaneous evaporation it deposited small crystals of citrate of iron. By concentration, it became black like ink, and ductile like hot resin, but brittle when cold. It tastes very astringent, and is very soluble in water.

Citrate of LEAD may be formed by adding a solution of citric acid to a solution of acetate of lead. The salt is in the form of a powder, and is nearly insoluble in water. According to Berzelius, it is formed of citric acid 34.5, and oxide of lead 65.5.

Citrate of LIME.—The formation of this salt has been already described at page 250. When dried, it is in the form of a white powder, nearly tasteless, and scarcely soluble in water. It is soluble, however, in its own acid, which accounts for the concentrated acid generally containing a portion of lime. It is a compound of lime 33, and citric acid 67. Or it may be said to consist of, 1 proportional of acid 58, and 1 of lime 28, making its equivalent number 86.

Citrate of MAGNESIA is readily formed by dissolving carbonate of magnesia in citric acid. It does not crystallize, but forms, according to Vauquelin, a white mass which rises in the vessel like a mushroom³. According to this chemist, it is composed of citric acid 66.66, and magnesia 33.34.

Citrate of MANGANESE.—Citric acid dissolves the black oxide of manganese, and produces, according to Professor Brande, white arborescent crystals⁴.

Citrate of MERCURY.—Citric acid will not dissolve metallic mercury; but with the red oxide it forms an insoluble white mass. A proto-citrate and a per-citrate may be formed with this metal; but they are both insoluble salts.

Citrate of POTASH.—To form this salt, nothing more is necessary than to dissolve carbonate of potash in citric acid, and con-

³ Fourcroy's *System of Chemistry*, vol. vii. page 283.

⁴ *Manual of Chemistry*, vol. iii. page 95.

centrate the solution by evaporation. It is extremely soluble, and crystallizes with difficulty. It was called the salt of *Riverius* in the old Pharmacopœias, and is still much used in medicine. It is deliquescent and decomposable by barytes and lime. Vauquelin, who paid considerable attention to this salt, found it to consist of citric acid 55.55, and potash 44.45.

Citrate of SILVER.—Silver is not acted upon by citric acid; it dissolves its oxide, however, and forms with it a salt in the form of a white powder, which has a harsh styptic taste, and is insoluble in water. Though white when it is first formed, it becomes, like other salts of silver, black by exposure to the light. It is a compound of citric acid 36, and oxide of silver 64.

Citrate of SODA.—This salt is formed by dissolving soda or its carbonate in citric acid. It has a faint and saline taste, and is difficultly crystallizable; but when crystallized, it requires nearly two parts of water for its solution. It crystallizes in six-sided prisms, or in hexahedral tables. It consists of citric acid 60.7, and soda 39.3.

Citrate of STRONTITES was formed by Vauquelin by the mixture of citrate of ammonia with nitrate of strontites. It is a crystallizable salt, and soluble in water.

Citrate of URANIUM has been formed by digesting oxide of uranium in citric acid. The salt crystallizes with difficulty, but it is soluble in water.

Citrate of ZINC.—Citric acid acts freely on metallic zinc or its oxide. Small brilliant crystals of citrate of zinc are formed which have a strong metallic taste, but they are scarcely soluble in water¹. The salt is a compound of citric acid 59, and oxide of zinc 41.

It would be improper to dismiss this subject, without adverting to the application and general USES of the citric acid.

Besides the common medicinal² purposes to which the citric acid is applied, such as the making of saline draughts, &c., it is often combined with opium to prevent the stupifying effects of that very powerful narcotic; and I have been told that it has been given with good effect to counteract such an over-dose of it as would otherwise have proved fatal.

Its operation in obviating the destructive power of this or some other powerful drug, was known to the ancients; for it is evidently alluded to in Virgil's *Georgics*, as may be seen in the motto prefixed to this Essay³.

¹ Fourcroy's *System of Chemistry*, vii. 284.

² Speaking of the medicinal uses, reminds me of what I have read respecting the effect of citric acid on milk. It is said that although it curdles the milk of most animals, it has not this effect upon human milk, whether used hot or cold. Voltelen *Obs. Chem. Med. de Lacte humano*. Traj. Batav. 1775.

³ See also Girtanner in *Annales de Chimie*, tom. xxxiv, p. 306.

In domestic economy the citric acid is employed with advantage as a condiment for a variety of food, it being more grateful than vinegar on account of the fine aroma derived from the essential oil peculiar to the rind of the fruits which produce it. Likewise for taking out iron-moulds or other stains of iron; as this metal is not only soluble in citric acid, but the solution is so permanent that it is not precipitated again by the application of soap, which sometimes happens when other salts are used for this purpose. It is useful also for removing spots occasioned by alkalis, or the alkaline earths, from scarlet cloth;—for making a solution of iron for bookbinders, to give the mottled appearance to the surface of calf-skin;—for improving that peculiar solution of tin which is employed for producing the most exquisite specimens of the scarlet dye;—for altering the hue of some colours which are exclusively used in the dyeing of silk;—for the preparation of the best Morocco leather;—and for improving candles, by whitening and hardening the tallow which is employed in making them.

A very considerable quantity of citric acid, in the form of lemon juice, is also consumed by the seamen of the British navy⁴. It was formerly bought in London, having first been submitted to the judgement of a respectable chemist, who was regularly employed for the purpose. As the managers of this department have found that it can be brought from Sicily at a much more reasonable price, and of the best quality, they now procure it from that island, and decline all other sources. To preserve it on long voyages, they generally put about 10 gallons of brandy to every 100 gallons of the juice, which has the effect of precipitating the mucilage, that otherwise would not fail, during an extended voyage, to throw the whole into a state of fermentation, and convert much of it into vinegar.

Dizé⁵ says that a lemonade of the most agreeable taste and appearance may be made by dissolving 40 grains of citric acid in a pint of water, with the addition of a sufficient quantity of refined sugar, and that it may be rendered fragrant by dissolving in it a small quantity of oleo-saccharum, prepared by rubbing a lemon on a lump of sugar. The sugar, by imbibing the volatile oil of the lemon, renders it perfectly soluble. By this means it is easy to preserve the volatile oil of any number of lemons. The oleo-saccharum thus obtained may be mixed in a mortar with a sufficient quantity of sugar; and when this has been dried by a very gentle heat, it may be kept in well stopped bottles-unim-

⁴ Lord Anson and Captain Cook were the first navigators who employed lemon juice on their ships' crew for the prevention and cure of the sea-scurvy.

⁵ Nicholson's 4to *Journal*, vol. ii. page 45.

paired for any length of time. This is preferable to the volatile oil of lemons obtained by distillation, because the fire often imparts an unpleasant or empyreumatic flavour to it.

Other domestic and economical purposes might be enumerated, to which citric acid is applicable, especially now that it can be kept in its crystallized state in every family, in which form it is liable neither to decay nor even to the slightest alteration.

Citric acid is principally consumed by the calico-printer, who uses it in several processes of his art, especially to discharge iron, and to preserve white grounds on certain parts of a pattern, by means of the property it has of resisting the operation of sundry dyes, as is more fully explained in the Essay on Calico-printing.

The person who first prepared this acid in large quantities in England, and chiefly for the use of the calico-printers, was Mr. Coxwell, late of Fleet-street, who sold it at a high price in the form of clean white crystals. With this the printers were supplied for many years; but when the demand became greater than he could well answer, he began to furnish them with the brown crystals, that is, with the acid in the first or second stage of crystallization, and consequently at a much lower price.

The discovery that citric acid can be used in a brown state for calico-printing occasioned the printers pretty generally to turn their attention to the preparation of the citric acid; and now most of the proprietors of the large establishments buy lemon juice for themselves, and use it in different states of concentration, according to the nature of the processes to which it is to be adapted.

For most of the styles of work in which citric acid is employed, they find that the common impurities in lemon juice are of very little consequence; and that when the juice itself has undergone no other process than that of being concentrated by the evaporation of a portion of the water it contains, it very well answers their purpose, and supersedes the use of the crystallized acid.

As there is always abundance of spare heat in every large calico-print work, the process of evaporation may be conducted at no expense: and if it be continued very slowly for some considerable time, the acid will be sufficiently concentrated, and this without waste. For when it arrives at a certain point of concentration most of the mucilage will be separated, one part of which generally rises to the surface, and the other precipitates.

It is time, however, to come to the particular point which first induced me to think of writing on this subject,—namely the knowledge of the circumstance, that the printers depend solely on the hydrometer for ascertaining the goodness of lemon juice. This made me very desirous of recommending to them some less fallacious guide.

Various reasons may be adduced to show the uncertainty of the hydrometer; but one or two will suffice. It is possible, for instance, that two parcels of juice may appear to differ very much, when examined by the hydrometrical test, from the difference of the quantity of mucilage, though the same parcels may be of equal goodness as to the produce of the crystals or real acid that may be procured from them. In like manner, a pipe of lemon juice may be sophisticated with other acids, so as to make it pass the hydrometer, and yet be worth little for the printer's use.

On these accounts it appears to me that there can be no safety in purchasing this article, unless the buyer avail himself of the use of chemical tests, especially as an experienced calico-printer has assured me that fine wheat flour is sometimes employed to adulterate lemon juice. It certainly may be so incorporated with the mucilage as to affect the hydrometer considerably.

Whenever, therefore, a parcel of lemon juice is offered for sale, the first thing should be to take its specific gravity by the hydrometer, or by means of a specific-gravity bottle, and note that down. Should it prove to be only of the specific gravity of about 1.0156, which is 16 ounces 4 drachms to the wine-pint, it may at once be rejected as not worth purchasing; for good juice varies from a specific gravity of 1.0312 (16 ounces 8 drachms) to that of 1.0625, or 17 ounces avoirdupois the wine-pint.

Should the parcel appear good by the hydrometer, take then, for the next experiment, a wine glass of the juice, dilute it plentifully with pure water, and add to it a few drops of a solution of acetate of lead as directed at page 252: this will produce an immediate precipitate, chiefly of citrate of lead, which should then be treated with a little pure nitrous acid, and the effect carefully observed; for, if the nitrous acid dissolve the whole of the precipitate, it will prove that the juice under examination contains no sulphuric acid. By proceeding in the same way with an acidulous solution of nitrate of silver, instead of acetate of lead, it will be seen whether the juice contains any muriatic acid; this and the sulphuric being the only two acids, except the acetic, that are ever likely to be employed in the adulteration of lemon juice. And if the presence of acetic acid is suspected, saturate the juice with carbonate of lime (whiting): as long as effervescence continues, filter the supernatant liquor, and drop into it, when clear, a few drops of oxalic acid in solution. If acetic acid is present, the liquor will contain acetate of lime, which earth will instantly be precipitated by oxalic acid, or even by sulphate of iron, the common green copperas. It should be observed, that what little malic acid it contains will have the same effect, so that a trifling precipitate may be expected even in good juice.

When it has thus been found that a sample of lemon juice contains no admixture of other acids, the next step ought to be to ascertain how much real citric acid any given quantity of such juice actually holds in solution. For though it may not have been designedly sophisticated by any extraneous matters, it may be very inferior from other causes, the extent of which can only be accurately discovered by the application of another chemical test.

For instance, the fruit of which it was made may have been gathered in an unfavourable month, after the descent of the heavy rains; or deteriorated by the spontaneous decomposition which is occasioned by age; or it may have been diluted with water; all of which may be apprehended, when it is not known how many hands the juice has passed through before it comes into the possession of the consumer.

The mode which naturally suggests itself of ascertaining this point, is by means of an alkali; for if it be proved by the foregoing tests that the juice contains no admixture of other acids, the amount of the crystals of citric acid which it will yield will be in exact proportion to the quantity of alkali which it requires for its saturation.

To adapt this theory to practice, all that is necessary is to select some alkali, such as pearl-ash, or the crystals of soda, of which a solution is to be made, something below the point of saturation; and when this has been filtrated through blotting-paper, and its specific gravity noted down, it will be ready for use, and should be carefully laid by, to have recourse to whenever occasion requires.

Let one thousand grains, or any given quantity, of the lemon juice be weighed out; and having previously balanced a phial of the solution of alkali in an accurate pair of scales, let a portion of the alkali be gradually added to the juice, which should be well stirred with a glass rod, or poured from one vessel to another, between every addition of the alkali. When the effervescence seems to grow less and less, a slip of the blue test-paper of the shops should be dipped in, to ascertain whether the mixture approaches the point of saturation. If the paper comes out red, it indicates that the acid still predominates, and more alkali must therefore be cautiously dropped in. After waiting a minute or two, to allow time for them to unite, another slip of test-paper is to be applied, and in this way repeated until the liquor has lost the power of occasioning any change in the colour of the test.

When this is the case, a slip of the test-paper reddened by very dilute vinegar should be dipped in, which will acquire a blue colour if too much of the alkali has been used; but if the liquor be brought to that state that it will cause no visible change

of colour in either the red or the blue litmus paper, the lemon juice may then be considered to be accurately saturated, and brought to the neutral state.

Now, replace the phial of dilute alkali in the scale, note down how many grains in weight are requisite to balance it, and call this the quantity of alkali expended in saturating the juice. When the operator has by previous experiment determined how much of his standard alkali is necessary to saturate any given quantity of the pure crystals of citric acid, he may at once, by the common rule of proportion, find how much solid citric acid is contained in any particular sample of lemon juice, which has been submitted to the tests already described.

In order to lay the foundation for a table of the quantities of pure alkali which are taken up by this acid in various states of concentration, I prepared some pure carbonate of potash, and found that 544 grains of such alkali are required to saturate one ounce avoirdupois, or 437.5 grains of pure dry solid crystals of citric acid; or, that one ounce and a quarter, omitting fractions, will render neutral one ounce of the crystallized citric acid. When this fact was ascertained, a foundation was laid for the construction of the Table No. I.

It is worthy of notice, that this test may be employed, not only in purchasing lime juice, but also in ascertaining the quantity of real acid in acid liquors of different degrees of concentration; a matter of considerable consequence to those printers who are desirous of being accurate in the proportion of acid which they employ in any particular style of work.

As some of the calico-printers in the North of England have found it advantageous to buy lemon juice instead of citric acid, and use it, after it is concentrated by evaporation, without further purification, as mentioned at page 266, I would here take the opportunity of suggesting, that when the juice has been partially concentrated by being exposed for some time to a very moderate heat, it would be useful to remove it to a situation where the evaporation will be suspended, and where it can remain undisturbed for a day or two, to give time for the thickened mucilage entirely to subside. It will then be advisable to draw the fluid from the precipitated impurities, by a syphon, or other means, and to pass it through a filter, before it be submitted to any further process of concentration.

Should the printer be desirous of purifying his lime juice by the chalk process as described at page 250, &c., I see no reason why he may not afterwards evaporate the fluid by some such method as is directed above, and use it in any stage of its concentration that may be most suitable, without being at the expense of reducing it to the solid form.

To render this more easy, I have constructed a table of the quantities of purified acid in a given portion of liquor of different strengths, as indicated by their specific gravity: and another table of a similar nature for the unfinished acid, or brown crystals¹, which I presume will be used with more propriety than the former; whenever it is necessary to ascertain the quantity of acid in the liquor of the first boiling. Both these tables will be found in the subsequent pages marked No. II. and III.

That nothing of importance may be omitted which respects this acid, the following circumstances, for which I am indebted to Dr. Thomson, may be added to the numerous facts already detailed in the preceding Essay:—

Chlorine converts gum into citric acid, according to the experiments of Vauquelin. This chemist passed a current of chlorine gas through a diluted solution of gum in water. In a few days almost the whole of the gum was acidified; and he detected citric acid by the formation of super-citrate of lime, soluble in water, and decomposable by oxalic acid. If nitric acid be slightly heated upon gum until it has dissolved it, and until a little nitrous gas is exhaled, the solution on cooling deposits *sacclactic* acid. *Malic* acid is formed at the same time; and if the heat be continued, the gum is at last changed into *oxalic* acid. Thus, no less than four acids are formed by the action of nitric acid on gum. We are, however, indebted to Mr. Cruikshanks for the most precise experiments on the quantity of oxalic acid obtainable from gum by nitric acid. By digesting 480 grains of gum with 6 ounces of nitric acid, he obtained 210 grains of oxalic acid. No artificial tannin is formed during this process.

¹ It will be perceived, that the specific gravity of the solution of brown crystals is greater than that of the pure crystals. This I apprehend arises from the brown crystals generally retaining a portion of sulphuric acid.

TABLES.

No. I.—A TABLE of the Quantity of pure Crystals of Citric Acid which may be obtained from different Parcels of Lime or Lemon Juice, as indicated by the Proportions of DRY *Salt of Tartar* required for their Saturation; one ounce measure of Lemon Juice being saturated by the test in each experiment.

Quantity of dry Salt of Tartar employed.	Quantity of Crystals of Citric Acid which may be obtained from one Gallon of such Juice.	Quantity of dry Salt of Tartar employed.	Quantity of Crystals of Citric Acid which may be obtained from one Gallon of such Juice.
Grains.	Ounces avoirdupois.	Grains.	Ounces avoirdupois.
4 $\frac{1}{4}$	1	42 $\frac{1}{2}$	10
8 $\frac{1}{2}$	2	46 $\frac{3}{4}$	11
17	4	51	12
21 $\frac{1}{4}$	5	55 $\frac{1}{2}$	13
25 $\frac{1}{2}$	6	59 $\frac{1}{2}$	14
29 $\frac{3}{4}$	7	63 $\frac{3}{4}$	15
34	8	68	16
38 $\frac{1}{4}$	9		

No. II.—A TABLE of the Solution of WHITE Crystals of Citric Acid.

Crystallized Acid.	Ounce Measures of Water.	Sp. Grav. at the Temp. 55 Degrees.	Avoirdupois Weight of the Wine-pint.		Quantity of Crystals dissolved by one Gallon of Water.		
	Oz.		Oz.	Dms.	Lbs.	Oz.	Dms.
1 Ounce Avoirdupois.	1	1.2187	19	8	8	0	0
	2	1.1395	18	3 $\frac{1}{4}$	4	0	0
	3	1.1016	17	10	2	10	10 $\frac{1}{2}$
	4	1.0799	17	4 $\frac{1}{2}$	2	0	0
	5	1.0663	17	1	1	9	9 $\frac{1}{2}$
	6	1.0575	16	14 $\frac{1}{4}$	1	5	5 $\frac{1}{4}$
	7	1.0494	16	12 $\frac{1}{4}$	1	2	4 $\frac{1}{2}$
	8	1.0433	16	11	1	0	0
	10	1.0352	16	9	0	12	12 $\frac{1}{2}$
	12	1.0298	16	7 $\frac{1}{2}$	0	10	10 $\frac{1}{2}$
	14	1.0250	16	6 $\frac{1}{2}$	0	9	2 $\frac{1}{4}$
	16	1.0216	16	5 $\frac{1}{4}$	0	8	0
	20	1.0162	16	4 $\frac{1}{4}$	0	6	6 $\frac{1}{4}$
	24	1.0135	16	3 $\frac{1}{2}$	0	5	5 $\frac{1}{2}$
	28	1.0115	16	3	0	4	9 $\frac{1}{4}$
	32	1.0101	16	2 $\frac{1}{2}$	0	4	0

To prevent the possibility of any misconception respecting the nature of this Table, it may be proper to state an example of its use. For instance, if it be required to examine a parcel of lemon juice by the dry salt of tartar, all that is necessary is to take an ounce measure, or the sixteenth part of a wine-pint of

such juice; and having noted the number of grains required for its saturation, to look for the same number in the second column of the first Table; and opposite thereto, in the third column, will be seen the quantity of crystals of citric acid which may be obtained from a gallon of such juice.

No. III.—A TABLE of the Solution of BROWN Crystals of Citric Acid.

Crystallized Acid.	Ounce Measures of Water.	Sp. Grav. at the Temp. 55 Degrees.	Avoirdupois Weight of the Wine-pint.		Quantity of Crystals dissolved by one Gallon of Water.		
	Oz.		Oz.	Dms.	Lbs.	Oz.	Dms.
1 Ounce Avoirdupois.	1	1.2656	20	4	8	0	0
	2	1.1640	18	10	4	0	0
	3	1.1171	17	14	2	10	10½
	4	1.0937	17	8	2	0	0
	5	1.0820	17	5	1	9	9½
	6	1.0664	17	1	1	5	5¼
	7	1.0566	16	14½	1	2	4½
	8	1.0526	16	13½	1	0	0
	9	1.0488	16	12½	0	14	3½
	10	1.0448	16	11½	0	12	12¾
	12	1.0390	16	10	0	10	10½
	14	1.0332	16	8½	0	9	2¼
	16	1.0312	16	8	0	8	0
	18	1.0273	16	7	0	7	1¾
	20	1.0254	16	6½	0	6	6¼
	24	1.0214	16	5½	0	5	5½
	28	1.0195	16	5	0	4	9¾
	32	1.0156	16	4	0	4	0

The Tables Nos. II. and III. are founded on actual experiments, undertaken for the purpose of ascertaining the specific gravities of the solutions of this acid at different degrees of concentration. A single example will be sufficient to explain their design.

Suppose a printer, who uses purified crystals of citric acid, should find that a solution of the specific gravity of 1.0162 is suitable for any particular purpose, he will learn, by reference to the Table No. II., that he may prepare a similar solution by dissolving one ounce of crystals in 20 ounces of water, or 6 ounces 6¼ drachms in one gallon of water.—The Table No. III. is constructed upon the same principle, and is intended for the use of those printers who employ the brown crystals.



CHEMICAL ESSAYS.

Plate 8.

D. Acid Pipe.
E. Tar Go.
G. Adapters.
H. Acid Basks.
P. Tar receiver.

*Chemical and Apothecary
Acid Apparatus.*

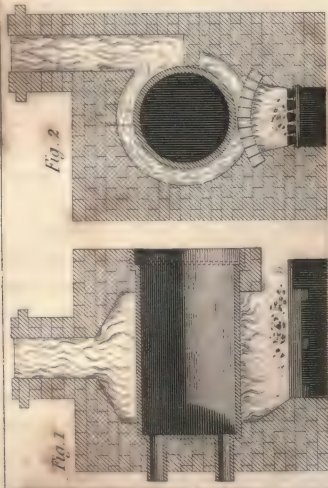


Fig. 1

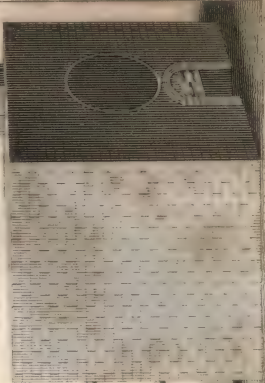


Fig. 4



Fig. 5

Fig. 3



Scale of Feet

1. Cylinder.
2. Diff. Section.
3. Elevation.
4. Outer Hopper.
5. Inner Shut.

WILLIAMS DEL.

ESSAY IX.

ON THE FIXED ALKALIES.

FROM the nature and origin of this class of bodies, it is evident that mankind must have arrived at a considerable degree of civilization before either of the alkalies could have been brought into general use: we shall, however, be able to demonstrate that they were employed in very remote periods of antiquity.

To those who are unacquainted with chemical subjects, and who have never had an opportunity of examining these substances, it will be impossible to convey a full idea of their nature and properties by any description that can be given of them; though it may be said, that when in a state of purity their chief characters are, an acrid and peculiar taste; that they have the property of changing blue vegetable juices to a green, and some yellows to brown; have a great affinity for animal and vegetable oils, with which they unite to form soap, the oils, or other fatty substances, being in this way rendered miscible with water; that they themselves are also very soluble in water; and lastly, which is one of their most decisive characteristics, that they readily combine with and neutralize the acids, forming neutral salts, which differ in their appearances and properties according to the nature of the respective acids, or alkalies, of which the salts are composed.

There are only four proper alkalies at present known, viz. the three fixed alkalies, and the volatile alkali. The former, which are known by the names of potash, soda and lithia, will constitute the principal subject of the present Essay.

The word *lixivium*, which was in use among the ancient Romans, is evidently derived from *lix*, which signifies a lye made with ashes: it therefore appears that the preparation of the fixed alkalies from the ashes of certain burnt vegetables, must have been known very early; especially as *lixa*, another Latin term, signifies a worker in ashes. Both of these words are used in the same acceptation by Columella¹ and also by Pliny², who flourished in the century immediately preceding the commencement of the Christian era.

Marcus Terentius Varro, the renowned Roman general, who wrote in the first century, affords other evidence to the same

¹ Lib. xii. cap. 41.

² Nat. Hist. lib. xiv. cap. 2.

purpose; for he tells us that some of the inhabitants upon the Rhine, being in want of sea-salt, used a substitute which they procured from some species of wood¹. These people had probably learnt a method of neutralizing the alkali which their forests afforded them, so as to form a salt that would answer some of the purposes to which our culinary salt is generally applied.

That the ancient Romans were acquainted with the fixed alkalies, or with one of them at least, is evident from a circumstance that occurred in exploring one of the streets of the ancient city of Pompeii, which was overwhelmed by an eruption of Vesuvius in the 79th year of the Christian era. On examining the excavations that were made on the spot where this famous city formerly stood, a complete soap-boiler's shop was discovered, with soap in it which had evidently been made by the combination of oil and an alkali. This soap was still perfect, though it had been manufactured more than seventeen hundred years².

Aristotle, who flourished nearly four hundred years before Christ, says that the ashes of certain burnt reeds and bulrushes, when macerated in water, yield a plentiful supply of salt³: and according to one of the sacred writers, who lived still earlier, his cotemporaries were not only acquainted with the alkalies, but had learnt to apply them to some of the common purposes of life⁴.

It does not with certainty appear which of the fixed alkalies was first known, though I conceive there is some reason for assigning the priority to soda as having been first in use for domestic purposes, as nature affords it to the inhabitants of several parts of the East without any contrivance or preparation of their own. It appears likewise to have been known by the term *nitrum*, and it is so described by several of the ancient writers.

In the ninth century, an Arabian author of the name of Geber describes soda very distinctly, and actually distinguishes it from potash. But, on the other hand, Pliny has as plainly told us that the Germans of his day used potash in making soap; so that the matter of priority will probably ever remain in uncertainty.

The word *alkali* is of Arabian origin, and is derived from Kali, the name of a species of vegetable from which soda is generally extracted. If we believe Albertus Magnus⁵, the word signifies *fæx amaritudinis*, "the dregs of bitterness;" the particle *al* having, as he says, been added by the Arabs, with the design

¹ Varro *De Re Rustica*, lib. i. cap. 7.

² See Miss Starke's *Letters from Italy*.

³ *Meteor* ii. cap. 3.

⁴ "Though thou wash thee with natron, and take thee much soap, yet thine iniquity is marked before me." *Jeremiah* ii. 22.

⁵ *Theatrum Chemicum*, ii. 470. Thomson, 8vo, 1804, vol. i. 463.

of expressing the superiority of the article obtained from the plant over the plant itself. In the days of Pliny the word *Kali* was, throughout Egypt, generally used to signify a certain vegetable abounding in alkaline salt, which grew on the seashore, on the banks of the Nile, and on the confines of the river Belus in Syria. The same word is in use also with us, and has the same signification.

The alkalies have a very peculiar taste, so different from that of all other bodies, that it will be no difficult matter for the student, when he has once made himself acquainted with it, to recognise them at all times by this peculiarity alone: but as these substances, when in a dry and pure state, are very corrosive, and would not fail to blister the tongue, it will always be necessary, for this purpose, to dilute them plentifully with water.

It is another property belonging to the alkalies, that they change many of the blue vegetable juices, such as the violet and mallow flowers, to a green; though if litmus be treated with either potash or soda, the colour will be rendered rather more intensely blue. By making this experiment, which may be done without any peculiar apparatus or expense, this characteristic of the alkalies will be imprinted on the mind so as never to be effaced.

Let the student prepare a solution of the potash or pearlash of commerce, and when a little of this is poured into a wine-glass containing one of the common *blue* vegetable decoctions, the whole will immediately be changed to a *green*. If a few drops of diluted sulphuric acid be then added, the alkali will be saturated, and the colour will in some measure be restored; and by adding a very little more of the acid, the whole fluid will assume a beautiful crimson. Hot water poured on a few slices of the red cabbage will produce a blue decoction, very suitable for this experiment; or a strong infusion of the dried flowers of the red rose will answer the same purpose.

Although the alkalies, as has just been stated, convert the *blue* vegetable juices to a green, they produce a deep brown in the vegetable *yellows*. Thus, if a few drops of the solution of potash or of soda be added to an infusion of turmeric, the yellow will instantly be converted to a brown; and this new colour will be permanent, unless it be afterwards treated with an acid, which has the power of restoring the original yellow; acids and alkalies, according to the predominance of either, having the property of alternately changing the hue of most vegetable colours. Hence the great use of this class of substances in the arts, especially in dyeing, and in the manufacture of several of the blue and green colours which are prepared for the painter.

The potash and pearlash of commerce were thought to be

pure simple substances, until Dr. Black, in the year 1756, satisfactorily proved that they all contain a considerable portion of carbonic acid. The readiness with which lime deprives this alkali of its carbonic acid may be shown by the following very simple experiment. Pour a little clear solution of carbonate of potash into a wine-glass of transparent lime water; and though both liquors were perfectly limpid as the purest water while separate, they will instantly become turbid on mixture; for the lime, absorbing the carbonic acid from the alkali, will be converted to carbonate of lime or chalk, which, being an insoluble compound, will precipitate in a white powder.

The largest consumption of the alkalies is chiefly in the making of soap and glass. The principal part of the kelp that is prepared on the coasts of Wales, Scotland, and Ireland, is employed in the first of these compounds, besides some thousand tons of barilla annually imported from the Continent, particularly from Spain, and from certain islands in the Mediterranean.

In the manufacture of soap, these rough alkalies are bruised by means of a horse-mill; and when mixed with a portion of quick-lime sufficient to deprive them of their native carbonic acid, or fixed air as it was formerly called, they are put as lightly as possible into large cast-iron vats capable of holding from one to five or six tons each.

When these vats are thus charged, water is let in until it rises an inch or two above the surface of the materials, care being taken that it run on in a regular gentle stream, so as not to render the charge too solid, which would prevent the lye from running properly through it. The design of the water is to dissolve the alkali that is contained in the kelp, or barilla, and in this way to separate it from the various insoluble matters which these articles always contain.

The lime does not impart any of its own properties to the lye or the soap, as is often believed; it is employed merely to deprive the alkali of the carbonic acid which has just been noticed, and which would incapacitate the alkali for forming that intimate union with the oil or tallow which is required to render the whole into a perfect soap, soluble in water.

When the charge has stood thus covered with the fluid for twelve hours or more, the wooden plug near the bottom of the vat is loosened, and the alkaline lye which has been formed is suffered to run off gradually into a large iron receiver, fixed underneath and below the floor of the manufactory. This is called lye of the first running; and, being the strongest, it is generally reserved for the last operations in the manufactory. The lixivium which has run from an adjoining but weaker vat, is now pumped upon that which has just been drained, and the

whole is suffered to remain at rest as before. The liquor is thus pumped from beneath one vat upon the contents of another, and that again is replenished from the adjoining one, day after day, in regular succession, until the last of the series, which has frequently been covered with simple water, is thought to be entirely spent. When this is the case, the plugs are at once taken out of the whole row of vats, and the contents are suffered to drain for some time, preparatory to their being *cast*, as it is called, which is performed in the following manner:—The ashes of the spent vat are first thrown out as a refuse article; and when this vat is entirely empty, the contents of the adjoining one are thrown in, and so on to the end of the row, or to the beginning of the series, when the first vat, being then empty, is re-filled with a new charge of kelp or barilla. The plugs are now replaced, and the ashes in each vat are again covered with the weak lye from the receiver that is immediately underneath it. Thus the whole of the alkali and alkaline salts are dissolved, and the lixivium formed at a small expense of labour. By suffering the ashes thus to drain themselves entirely dry, and then casting them with large shovels into another vat, such parts as may have become conglomerated are broken, so that every thing which is soluble has a chance of coming in contact with the fluid, and of being dissolved by it.

This narrative might perhaps have appeared with more propriety in an essay upon soap-making; but while treating expressly on the fixed alkalies, I was desirous of describing the method by which they can be rendered caustic at the least expense.

The alteration which is produced in the alkalies of commerce by the admixture of quick-lime is so manifest, and is attended with such important consequences, that the circumstance ought never to be forgotten by those who are engaged in any of the manufactories where large quantities of potash or soda are consumed: for in some, the quality of the manufactured article is much influenced by the state of the alkali; and in others, very great savings might be made by using caustic potash, or soda, in cases where the mild alkalies are now employed.

Many instances of these peculiar effects might be adduced: but I shall select one from the deterative property of the alkalies, that will sufficiently elucidate the practice which I am now attempting to enforce.

In scouring woollen yarn to free it from the oil which is combined with it in combing and spinning, it is no uncommon thing for the workmen to prepare a large boiler of lye, by dissolving American or Russian pearlsh in water, by means of heat,

When this liquor is hot, they immerse their brown yarn in it, and soon find it sufficiently freed from the oil and other filth that is attached to it. More is then immersed, but this takes a longer time to become clean; and the next parcel longer still; till at length it is so far spent as to have little or no effect upon the yarn, and is therefore suffered to run away to make room for a fresh lixiviation, although one half of the alkali in the former one is not consumed. Instead of proceeding in this way, let the workman mix a quantity of potash with one-fourth of its weight of fresh burnt quick-lime, (if pearlash be used, *one-half* its weight of lime should be taken,) put it into a vat, or into an iron pan, and then by the addition of water make a lixivium from it, as described above, and put only so much of this into the hot water as is necessary to scour that quantity of wool or yarn which is usually cleansed at once. Then let him add a few quarts more for the next parcel, and proceed in this way until the whole be finished, and he will find that any given quantity of work may be done with more expedition, and with less than half the alkali that is usually employed.

The lye made in the common mode operates very well at first, because a portion of the alkalies of commerce is generally in a caustic state; but as soon as this is saturated with the oil of the yarn, the remaining, and often the greater part, having no effect in the way they use it, is thrown away as useless, and is a total loss to the manufacturer. Many thousand pounds, I believe, are thus lost to the community annually, which might be saved by a general knowledge of this simple fact, *that alkalies will not combine with oleaginous matter, unless they are actually in a state of causticity*. The greater part of our American pearlash is combined with a very large portion of carbonic acid, and therefore it is not in a condition to combine with oil; but let it be divested of this acid, and it will not only form an intimate union with whatever oil or grease it comes in contact with, but it will render these impurities so completely soluble in water, that the whole will be as easily washed out from the yarn, and dissolved, as if it were sugar or salt.

Potash, as has before been mentioned, is prepared from the ashes of burnt wood, and is chiefly manufactured in those countries where there is an abundant supply of timber. It is observable, that in the middle of the last century it was not known how to make either potash or pearlash in any part of North America, equal in quality to that which had usually been imported from Russia. This was, however, at length effected by the persevering endeavours of a Mr. Thomas Stephens, who about the year 1753 received a grant from the Parliament of

England for his encouragement¹. The Russian method of making potash from large wood is fully described by Boerhaave in his *System of Chemistry*²: he has also given ample directions, in the same work, how various smaller vegetables may be managed in different circumstances, so as to be burnt for the production of potash; and though there may be few cases in which his processes would answer, in this country, on a large scale, yet a perusal of his narrative will not fail to give the reader a very correct idea of the methods for obtaining this singular substance. More economical directions, however, and perhaps the best hitherto devised, may be seen in the *Annales de Chimie*, tom. xix. page 157—193.

It has generally been imagined that the alkali which is procured from vegetables is the creature of fire; but I know of one case (and there may be many others), in which vegetables are employed for the sake of the alkali they contain, without previously burning them. I refer to the operation of fulling woollen cloth.

When woollen cloth comes from the hands of the weaver, it is carried to the fulling mill, where it undergoes a long-continued beating by ponderous wooden hammers, which are moved with considerable force by a large water-wheel. By this treatment the cloth becomes considerably thicker, closer, and better; losing in its length and breadth exactly in proportion to its increased thickness. But it is rather a curious circumstance, that no woollen cloth will thicken by this operation until it be divested of the oil or grease which the wool had acquired in the process of combing and carding. To effect this, the following articles are made use of, viz. an earth which is principally brought from the county of Kent, called fullers'-earth, common hard soap, and a portion either of potash, or the crystals of soda.

In the county of York, however, where there are many hundreds of poor weavers who work in their own small cottages, and produce perhaps one piece of cloth only in a week or a fortnight, it is customary for them to take it to a public mill, with the necessary quantity of scouring materials, and there to superintend the operation, until the cloth is brought to that thickness which they conceive will occasion it to sell most to their advantage.

Now I understand it is no unusual thing for those poor people who wish to avoid the expense of buying alkalies, to send their

¹ See *The Method and plain Process for making Potash*, by Thomas Stephens, 4to, with plates, London.

² Dallowe's edition of Boerhaave's *Elements of Chemistry*, vol. i. page 443, and vol. ii. page 28—35.

wives and children to an adjoining common to collect *fern*, which they throw into the mill with the piece, where its alkaline juices are expressed and worked into the cloth: and that by this as good an effect is produced as if soda or potash had been employed. And in other cases, where soap and alkali have been used, and too small a quantity of these has been taken, so that the cloth will not thicken sufficiently, a small parcel of fern will occasion the operation to commence, and it will then go on as well as could be desired. Some of the lower class of weavers derive, as I have been told, considerable advantage from their knowledge of this very valuable plant¹.

Potash may also be procured from the ashes of burnt peat: but this is not a source from which it is generally obtained; nor do I know that the method is at all practised any where but in the Highlands of Scotland, where the poor inhabitants have learnt how to make the soap for their domestic uses from the ashes of their own peat fires.

Potash may likewise be obtained from saltpetre, by heating it sufficiently with charcoal, or any carbonaceous matter that will decompose its acid. In this way one hundred weight of nitre will yield nearly half a hundred weight of pure potash; and whenever the relative prices of American potash and nitre will admit of it, the latter substance may be employed with profit for the production of this alkali. During our dispute with America, when the importations of pot- and pearl-ash were so small as to occasion a considerable advance on the customary prices of those articles, a large quantity of saltpetre was consumed in Great Britain for the above purpose; and for the *finer* kinds of flint glass, saltpetre may generally be substituted for potash with advantage.

Potash has been obtained in Germany, in pretty large quantities from the pyroligneous acid, by pouring this acid on wood ashes, and then fluxing the whole in a furnace of brick or stone. The process is described by Glauber, in his *Miraculum Mundi*, with considerable minuteness². Where saw-dust, straw, the tendrils of the hop, or bean-haums can be had in abundance, it might perhaps be advantageous to soak such materials in this acid, and then to burn and flux the whole into a saleable ash. But the oil should, if possible, be previously separated as much as possible from the pyroligneous acid.

Macquer relates, that in some parts of Germany potash is prepared from the same parcels of wood of which charcoal is

¹ See a paper by Monge on the Fulling of Woollen Cloth in the sixth volume of the *Annales de Chimie*, pages 300—311.

² Glauber, *Chemical Works*, folio, page 188.

made. A number of tubes made of plate iron or of copper, are so disposed in the pile of wood intended to be burnt into charcoal, that the acid, &c. is collected in reservoirs; and when the oil is separated the fluid is boiled in iron vessels, and the residuum is converted by calcination to an alkali³.

Potash is a component part of pumice-stone, and of some other mineral productions. Professor Abilgaard found that this alkali formed also a constituent part of animal blood⁴; but it seldom occurs in other animal substances, except in very minute quantities.

Before I close this account it may be useful to remark, that the buyers of American potash generally prefer that which breaks red, which is, as I apprehend, a mere prejudice; for I have reason to think that this colour arises chiefly from the presence of sulphur, and perhaps oxide of iron, neither of which can be of any use where a good alkali is required. I have ascertained that some English makers of potash who are acquainted with this effect of sulphur, designedly add a portion of that substance to their ash, while it is in a state of fusion; and by taking a little from the melted mass after every addition of the sulphur, and suffering that to cool for examination, they are easily enabled to bring the whole to that colour which will best suit the market.

Whenever this alkali is employed for nice purposes, the article called *pearlash* is generally preferred to potash. This is prepared by a long continued calcination of potash, at a low heat, whereby the sulphur and carbon which it contains are mostly burnt off. But as all the *pearlash* which comes from Russia and America contains a considerable proportion of neutral salts, it has long been, and still continues to be, our task to deprive it of these adulterations. And lately, several persons in various parts of this kingdom have established manufactories for preparing this alkali, and have produced considerable quantities, and comparatively in a state of great perfection, from various chemical residuums, which were formerly rejected as of no value.

Having thus fully treated on the history and origin of potash; on its various sources foreign and domestic; and on its nature and properties,—it will now be proper to give some account, however concise, of the several salts which are formed by its means, or which contain potash as one of their principal ingredients.

Acetate of potash, formerly called digestive salt of Sylvius.—It

³ See the article "Alkali," in Macquer's *Chemical Dictionary*, vol. i.

⁴ Parkinson's *Memoranda Chemica*, fourth edition, 1807, page 11.

is in the form of plates or prismatic crystals. These dissolve in their own weight of water at 60°. The solution has an acrid saline taste. The salt is composed of 1 proportional of potash 48, and 1 of acetic acid 50, making its equivalent number 98.

Ammonio-sulphate of potash.—This salt is formed by adding ammonia to the bi-sulphate of potash. The process is described by Link in Crell's *Annals* for 1796, vol. i. p. 26. It has a bitter taste like the common alkaline sulphates, and crystallizes in brilliant plates, which are not altered by exposure to the air. The salt consists of sulphate of potash 88, and sulphate of ammonia 57.

Antimoniate of potash.—This is a white powder possessing an acrid and metallic taste. It dissolves in boiling water, but is scarcely acted upon by cold water. According to Berzelius, it is composed of antimonious acid 79.2, and potash 20.8.

Antimonite of potash.—In an Essay on Chemical Nomenclature, Berzelius states this salt to be composed of antimonious acid 76.6, and potash 23.4. See Nicholson's *Journal*, vol. xxxv. p. 44. This salt is insoluble in cold, but soluble in boiling water.

Arseniate of potash.—This salt is formed by saturating arsenic acid with potash. It is deliquescent when exposed to the air, and is incapable of crystallization. It renders syrup of violets green, but has no effect on an infusion of turnsole.

Arsenite of potash.—This is a very soluble and incrustable salt. It is formed by boiling white arsenic in a solution of potash. This salt is the most important ingredient in Fowler's *tasteless ague drop*.

Benzoate of potash.—This is a deliquescent salt, very soluble in water. If this salt be digested with benzoic acid, a bibenzoate will be produced in acicular and lamellar crystals, which require ten parts of cold water for their solution. See Bucholz, *Annales de Chimie*, vol. lxxxiv. page 311.

Bicarbonate of potash.—This salt is usually made by passing carbonic acid gas into a solution of potash in water, and evaporating the fluid to the point of crystallization. The crystals which separate are in the form of four-sided prisms, with diheral summits. The dry salt consists of 2 proportionals of carbonic acid 44, and 1 of potash 48. When crystallized it consists of dry salt 92, and water 9.

Bichromate of potash crystallizes in rectangular tables of an exquisitely beautiful orange colour much used as a pigment and by the calico-printers. It consists of 2 proportionals of chromic acid 104, and one of potash 48.

Binarseniate of potash.—A salt formerly known by the name of the *arsenical neutral salt* of Macquer. It may be formed by

adding arsenic acid in excess to potash, and evaporating the solution. The salt appears in quadrangular crystals, terminated by four-sided pyramids. It is much employed for the cure of agues. It is soluble in water; and, like the acids, it changes the blue juices of vegetables to a red. It is composed of 1 proportional of potash 48, and 2 of arsenic acid 124.

Binoxalate or superoxalate of potash is formed merely by dissolving the crystals of oxalate of potash in oxalic acid. It also exists ready formed in wood-sorrel, the *Oxalis acetosella* of Linnaeus. When extracted it is sold under the improper name of *essential salt of lemons*. It is composed of 1 proportional of potash 48, and 2 of oxalic acid 72.

Biphosphate or superphosphate of potash.—This salt is easily formed by dissolving phosphate of potash in phosphoric acid, and evaporating the liquor to the point of crystallization. It crystallizes in small striated prisms, which are exceedingly soluble in water. The salt when dry has the specific gravity of 2.851. Hassenfratz, *Annales de Chimie*, tome xxviii. page 14.

Bisulphate or supersulphate of potash.—This salt, which is the *arcantum duplicatum* of the old chemists, may be formed by dissolving the common sulphate of potash in hot sulphuric acid. It generally separates from its water of solution in thin rhomboidal crystals, which are soluble in two parts of water at 60°. This salt contains twice as much acid as the sulphate of potash.

Bitartrate or supertartrate of potash is the cream of tartar of commerce. It exists in the juice of the grape, and when deposited on the sides of wine-casks is known by the name of *argol*. It is composed of 2 proportionals of acid 134, and 1 of potash 48. This salt requires 120 parts of water at 60°, or 30 parts at 212°, for its solution.

Boletate of potash.—The boletic acid is obtained from the juice of the *Boletus pseudo-igniarius*. The boletate of potash was formed by Braconnot: but all that he has said of it is, that it is very soluble in water, that it is not easily procured in crystals, and that other acids precipitate the boletic acid from it. See *Annales de Chimie*, tome lxxx. page 278.

Borate of potash.—This salt may be obtained either in a dry mass or crystallized. The crystals are quadrangular prisms, unalterable by exposure to the air. The properties of this salt are little known. Berzelius attempted to ascertain its constituent parts, but without success. It may be procured by boiling boracic acid in a solution of potash.

Camphorate of potash may be made by saturating a solution of carbonate of potash with camphoric acid.—The salt crystallizes in regular hexagons, which are soluble in about 100 parts of

water at 60° , or in 25 parts at 212° . It is soluble in alcohol, and the solution burns with an intense blue flame.

Carbonate of potash.—Large quantities of this salt are imported into this country under the names of potash and pearlash—articles very generally known. It is sometimes procured from nitre, and also from tartar. If these salts are submitted to a red heat with carbonaceous matter, their acids are separated thereby, and carbonate of potash is formed. It consists of carbonic acid 22, and potash 48.

Chlorate of potash, formerly called hyper-oxy muriate of potash, is made by passing a current of chlorine gas into a solution of potash, or carbonate of potash in water. It crystallizes in thin plates. When mixed with sulphur or phosphorus it explodes by trituration. If concentrated sulphuric acid be dropped upon a small quantity of this salt, the decomposition will be so rapid as to produce violent explosion with bright flame. It is upon this principle that the instantaneous light boxes are formed, the bottle containing asbestos saturated with the acid, and the matches being coated with a mixture of chlorate of potash and sugar. See an account of many of these experiments in the *Chemical Catechism*. This salt is composed of 1 proportional of chloric acid 76, and 1 of potash 48.

Chromate of potash crystallizes in slender prisms; it is of an intense lemon colour, and decomposes most of the metallic salts, forming with those of lead a beautiful yellow much used as a pigment. It is composed of chromic acid 52, and potash 48.

Citrate of potash.—This salt has been already described in the Essay on Citric Acid, page 263.

Columbate of potash.—By boiling the columbic acid in a solution of potash, this salt is produced in white scales resembling those of boracic acid. When the mineral acids are added to a solution of this salt, the columbic acid is separated in the form of a white powder. See Hatchett, *Phil. Trans.* for 1802.

Ferrocyanate of potash is a salt much used in calico-printing. —It may be prepared by digesting Prussian blue in a hot solution of caustic potash. It is a triple salt, composed of hydrocyanic acid, potash, and oxide of iron. It crystallizes in fine cubic and tabular crystals of a bright yellow colour, and unchangeable in the air. See the Essay on Calico-printing.

Ferrotartrate of potash may be made by digesting iron filings with tartar, in the proportion of one part of iron with two parts of tartar, and then boiling the mass in a proper quantity of water to dissolve the triple salt which is formed by the process. In the old pharmacopœias this salt was known by the name of *Tartarized tincture of Mars*.

Fluate of potash.—This salt may be formed by the combination of pure potash with fluoric acid. Heat is given out on the mixture, and by subsequent evaporation the salt is obtained. It is deliquescent, and very soluble in water. It may be decomposed by the mere addition of sulphuric acid, which combines with the alkali and liberates the acid in the form of vapour.

Hydrate of potash.—The fixed alkalies contain a considerable portion of water, even after they have undergone a red-heat. Hence the alkalies of commerce are always in the state of hydrates. The hydrate of potash consists of 1 proportional of potash 48, and 1 of water 9, making its equivalent number 57.

Hydriodate of potash is formed by dissolving carbonate of potash in hydriodic acid. The constituents of this salt are, hydriodic acid 125, and potash 48.

Hydroguretted sulphuret of potash.—This salt may be formed by mixing flour of sulphur with a solution of hydro-sulphuret of potash, and digesting the mixture in a gentle heat. Thus an additional portion of sulphur will be dissolved, and an hydroguretted sulphuret of potash formed, which is a salt of a deep yellow colour, with a very pungent and bitter taste, and a very offensive smell. It may also be formed by boiling flowers of sulphur in a weak solution of caustic potash.

Hydrosulphuret of potash may be produced by saturating potash with sulphuretted hydrogen. The fluid will be colourless and transparent, and on evaporation will yield crystals not unlike those of sulphate of soda. See Vauquelin, *Annales de Chimie*, tome xlii. page 40.

Hypophosphite of potash.—This is a deliquescent salt, very soluble either in water or alcohol. When submitted to heat, phosphorus and phosphuretted hydrogen escape, and the salt is converted to phosphate of potash. See Dulong, *Annales de Chimie et Phys.* tome ii. page 142.

Hyposulphite of potash.—This salt is prepared by treating hydrosulphuret of potash with liquid sulphurous acid, and evaporating the solution to the point of crystallization. On cooling, needle-formed crystals are produced, which have a bitter taste, and deliquesce when exposed to the atmosphere.

Iodate of potash.—This is a white salt in very minute crystals. It is not altered by the air; but if heated to redness, oxygen gas is given off, and iodide of potassium is produced. One hundred parts of water at $14\frac{1}{4}^{\circ}$ centr., or $57\frac{1}{2}^{\circ}$ of Fahrenheit, will dissolve 7.43 parts of this salt. Gay-Lussac, *Annales de Chimie*, tome xci. page 74.

Lactate of potash may be obtained by decomposing carbonate of potash with lactate of lime. The salt has the appearance,

when the water is abstracted by evaporation, of a yellowish brown gum of a soft consistence. It is soluble in heated alcohol.

Malate of potash is a deliquescent salt, and so extremely soluble in water as to be incapable of crystallizing.

Meconiate of potash forms itself in four-sided tables, which are soluble in two parts of water at 60° , and composed of 60 parts potash, 40 meconic acid, and 13 water. See Brande's *Manual*, vol. iii. page 71.

Mellate of potash is a salt which crystallizes in elongated prisms. By a further addition of the acid, a supermellate may be formed. Vauquelin, *Annales de Chimie*, tome xxxvi. page 209.

Molybdate of potash may be formed by digesting molybdic acid in a solution of potash. The salt crystallizes in small rhomboids, running into one another. These are soluble in hot water: but the molybdic acid may be precipitated therefrom by the addition of sulphuric or muriatic acid. See *Annales de Chimie*, tome viii. page 106.

Muriate of potash.—This salt when dry is in fact a chloride of potassium, consisting of potassium 40, and chlorine 36. It crystallizes in cubes which deliquesce slightly in the atmosphere. In philosophical chemistry it is very much employed to produce artificial cold.

Nitrate of potash, or what is usually called Saltpetre, is produced naturally in some particular districts in all hot countries: but that which is consumed here is chiefly brought from the East Indies. It crystallizes in hexagonal prisms. One hundred parts of water at 60° dissolve fourteen parts of this salt, and boiling water dissolves more than its own weight. This salt is composed of nitric acid 54, and potash 48.

Nitrite of potash is a salt which was first observed by Scheele. His process for preparing it is to fill a large crucible with nitre, and keep it in a red-heat for half an hour. During this time a portion of oxygen escapes, and what remains in the crucible is *nitrite* of potash, a salt which will deliquesce when exposed to the action of the air.

Oxalate of potash.—This salt is formed by dissolving potash in a solution of oxalic acid. It crystallizes in flat rhomboids, soluble in three parts of water at 60° . It is composed of 1 proportional of oxalic acid 36, and 1 of potash 48.

Oxychlorate of potash, which is a very insoluble salt, crystallizes in elongated octoëdrons. It consists of 1 proportional of oxychloric acid 92, and 1 of potash 48. It is unalterable in the air, and possesses no bleaching properties whatever.

Phosphate of potash.—This salt may be produced by adding carbonate of potash to hot phosphoric acid until the point of

saturation be attained. If the solution be much concentrated and then suffered to cool gradually, small prismatic crystals of phosphate of potash will be obtained, consisting of 1 proportional of potash 48, and 1 of phosphoric acid 28.

Phosphite of potash.—This is a deliquescent salt, incapable of crystallization. Its properties, or even its component parts, are not yet known.

Quadroxalate of potash was discovered by Dr. Wollaston. When the Bincoxalate of Potash is digested in dilute nitric or muriatic acid, a part of the alkali is taken up, and a salt remains consisting of four times as much oxalic acid as exists in oxalate of potash. It is formed of four proportionals of oxalic acid 144, and one of potash 48, making its equivalent number 192.

Sacclactate of potash.—Scheele has treated on this salt in his Essay on the Sugar of Milk. He describes the salt to be in small crystals soluble in eight times their weight of water at 212°.

Silicate of potash was known to the old chemists. It may be prepared by fusing three parts of good potash with one part of ground silica, both calculated by weight. The resulting compound forms a kind of glass on cooling which is soluble in water. The solution thus formed is called *liquor silicum*.

Sorbate of potash.—The sorbic acid was discovered in 1815 by Mr. Donovan in the juice of the berries of the mountain ash. United with potash this acid forms two distinct salts, viz. the *sorbate* of potash which is incrySTALLIZABLE, and the *bisorbate*, which gives permanent crystals soluble in water, but insoluble in alcohol.

Suberate of potash is best prepared by digesting suberic acid with a solution of crystallized carbonate of potash. The salt crystallizes in prisms, and these are very soluble in water.—*Annales de Chimie*, tome xxiii. page 52.

Subphosphate of potash.—This salt has been formed by fusing pure potash, with the phosphate of this alkali, in a platinum crucible. It is either a white solid, or a white powder, according to the mode of its preparation.

Succinate of potash is a salt which crystallizes in small prisms, deliquesces in the air, and is very soluble in water. Its taste is saline and bitter.

Sulphate of potash.—This salt is produced as a residuum in large quantities by the makers of nitric acid, and is sold under the name of *sal enixum*. It has a saline bitter taste, and when dissolved in water crystallizes for the most part in short six-sided prisms, terminated by hexangular pyramids. It is composed of 40 sulphuric acid, and 48 potash.

Sulphite of potash.—This salt, which was formerly known by the name of the sulphurous salt of Stahl, may be formed by passing sulphurous acid gas into a saturated solution of very pure

carbonate of potash, until the effervescence entirely ceases. The solution becomes warm during the combination, and the salt crystallizes on cooling in the form of rhomboidal plates. These by exposure to the air are converted to sulphate of potash.—See a memoir by Fourcroy and Vauquelin in Nicholson's *Journal*, 4to, vol. i. page 317.

Sulphuret of potassium is formed by the fusion of a mixture of sulphur and potash. This was formerly called liver of sulphur, and consists of 1 proportional of potassium 40, and 1 of sulphur 16.

Tartrate of potash is formed by adding a quantity of potash to the bitartrate of potash sufficient to saturate the excess of acid. It is called soluble tartar, and is used in medicine as an aperient. It consists of 1 proportional of acid 67, and 1 of potash 48.

Tartrate of potash and antimony.—This is that important combination usually known under the name of emetic tartar. It is a white salt, requiring 14 times its weight of cold water, or two parts of water at 212° , for its solution. It is composed of 2 proportionals of tartaric acid 134, 2 of protoxide of antimony 106, and 1 of potash 48, making its equivalent number 288.

Tartrate of potash and soda, or Rochelle salt, is usually prepared by adding the crystals of carbonate of soda to the super-tartrate of potash, until the excess of tartaric acid is saturated. It is then purified by repeated crystallizations, and appears in irregular prismatic crystals. It consists of tartrate of potash 115, and tartrate of soda 99.

Tellurate of potash.—If oxide of tellurium be mixed with nitre, and the mixture be exposed to heat, the nitre first melts without acting on the oxide; but at the temperature in which the oxide begins to liquefy, it decomposes the nitre with a violent effervescence, the nitric acid is driven off, and the oxide dissolves in the potash. The mass when cold very much resembles an enamel. It dissolves in boiling water, and the solution on cooling deposits an imperfectly crystallized white powder. This is tellurate of potash. It has a slight metallic taste, and acts feebly as an alkali on vegetable blues.—Thomson, vol. ii. page 665. Berzelius, Nicholson's *Journal*, vol. xxxvi. page 130.

Tungstate of potash is a salt which may be prepared by dissolving the oxide of tungsten in a strong solution of carbonate of potash. When this saturated solution is concentrated by evaporation a white powder falls down, which is the tungstate of potash. This salt deliquesces when exposed to the air, and consequently is very soluble in water.

Urate of potash.—This salt is stated by Dr. Thomson to be a white powder nearly similar to uric acid in appearance and solubility. It is also soluble in a lye of caustic potash.

Zumate of potash.—Zumic acid is obtained by a peculiar process from rice. It was first described by Braconnot, but the name which it now bears was given by Dr. Thomson. The zumate of potash is a deliquescent salt, incapable of crystallization, and soluble in alcohol.—*Annales de Chimie*, tome lxxxvi. page 84.

The other alkali of which we have to treat is SODA, which is also known by the names of natron, barilla, mineral alkali, and fossil alkali. This substance is met with in abundance, and even used for various purposes, in China, Persia, in the environs of Smyrna and Tripoli, and in general all over the East, as well as on the northern coast of Africa, in Hungary, and Siberia. It likewise occurs in the state of carbonate of soda in many of the mineral waters of Germany.

Native soda is also found in large quantities, on the surface of the ground, in the plains of the Delta in Egypt, from whence it is brought to this country under the name of natron. It occurs in the same state in the East Indies, and in the islands of Sicily and Teneriff. These islands furnish us likewise with a large quantity of soda, in the form of barilla, which is chiefly consumed in the soap trade, as already mentioned.

Barilla is likewise imported in very considerable quantities from Spain. This is made by the incineration of the *salsola soda*, a marine plant, which is so highly valued by the Spaniards, that the exportation of the seed is, by the law of the country, punishable with death. It is cultivated with great care in the neighbourhood of Alicant and Carthage, for the production of barilla; but that of Alicant is generally the most esteemed.

And here we must not omit to mention the manufacture of kelp upon our own shores, and which is so considerable as to furnish the English market with many thousand tons of soda annually. The manufacture of this article was introduced into the Highlands of Scotland about the year 1730, by a gentleman of the name of MacLeod, who brought the art of cultivating it from Ireland.

Since the manufacture of kelp has been introduced into the Orkneys, small farms of forty pounds a year have risen to 300*l.* a year¹; and “it is said that Lord MacDonald of the Isles realized ten thousand pounds a year from his kelp shores alone, which his ancestors looked upon as of no value whatever. So much indeed are the proprietors of the sea-coast now impressed with the value and importance of the kelp manufacture, that they have found the means of producing it on the very sands. They place stones within flood-mark of the sea, which are soon covered with *ware*,

¹ Jameson's *Account of the Scottish Isles*, vol. ii. page 244.

as it is commonly called, and which is the vegetable substance from which kelp is made ¹.

The British kelp is prepared by the burning of various plants of the genus *salsola* of Linnæus, (the common sea-wrack,) and similar to the *salsola soda* of the Spaniards; but the article which is procured from these plants is much inferior to barilla, inasmuch as it contains a large portion of neutral salts, a quantity of potash, and a much larger proportion of carbonaceous matter than is generally found in the former article.

In making either barilla or kelp, the weed is collected into heaps to ferment; it is then spread to dry in the air, and is afterwards burnt to ashes in ovens made with brick or stone, and built within the ground. By increasing the heat, the alkali in the ashes melts, and combines the whole into one solid mass. When cold, it is broken up with iron bars into large ponderous masses, and in that state it is sent to market. The best account that I have seen of the manufacture of kelp is in Jameson's "*Mineralogy of the Scottish Isles*," 4to, vol. ii. page 244. See also my own "Prize Essay on Kelp and Barilla" in the fifth vol. of the *Transactions of the Highland Society of Scotland*, pages 65—122.

It has long been a desideratum with the soap-makers and other purchasers of kelp and barilla, who happen to have no knowledge of chemistry, to find a method of ascertaining the exact portion of alkali in any sample which may come under their examination; and as no accurate directions have been published, at least that I have seen, I shall here give a detail of the mode which I have followed for several years, in many hundreds of cases, and which has in no instance deceived me. In preparing for the analysis, it will be necessary to attend to the following directions.

In the first place, procure a pair of good small scales with a set of decimal weights from one grain to a thousand grains; a graduated drachm measure, also a two-ounce measure, both of glass; a strong phial that will pour well; some litmus-paper of both kinds, viz. blue and red; a bottle of the solution of muriate of platinum; and some sulphuric acid diluted with pure water until it be reduced, when cold, to the specific gravity of 1.100.

When any parcel of kelp or barilla is to be examined, it will be proper to select as fair an average sample as possible. This can only be done by taking several lumps from different parts of the heap, by breaking a small piece from each of these lumps, and mixing them with a fair proportion of the small which may belong to the lot. The sample should then be pulverized in an iron mortar, that the whole may be more completely mixed; and a small quantity of this, say about an ounce, should be returned

¹ *Tradesman's Magazine*.

into the mortar and ground to an impalpable powder, that the alkali may be dissolved out of it with greater ease and certainty. Things being thus prepared, the analysis is to be proceeded with in the following manner :

Take the weight of one hundred grains of the alkaline powder, put it into a convenient vessel, and pour over it a two-ounce measure of pure water. Stir the mixture with a piece of glass, repeating it now and then during the space of a few hours. When the insoluble matter has been suffered to subside, pour the supernatant liquor upon a paper filter, and add another measure of water to the residuum, which should be well stirred once or twice, and then be suffered to remain as before. It is necessary to attend to the circumstance of filtrating the solution : otherwise there might be a portion of lime or carbonate of lime in it, which would absorb part of the acid employed in the analysis, and occasion an inaccurate result. When this lixivium has been thus filtrated, the residuum itself should be put upon the filter, and small portions of water poured over it occasionally, until the water passes through it devoid of taste and colour.

These solutions are now to be mixed, and put into a convenient vessel, in which they should boil until the whole is reduced to about two or three ounces, when it will be sufficiently concentrated for the examination, which should be conducted in the following manner :

Take about two ounces of diluted sulphuric acid, as above mentioned, of the specific gravity of 1.100; and having weighed it accurately, together with the phial, note down the united weight of both in grains. Then pour a portion of the acid very gradually into the alkaline solution, and stir it well with a glass rod, till the effervescence occasioned by the escape of the carbonic acid has ceased.

A slip of the reddened litmus-paper should now be dipped into the solution; and if this becomes blue, it shows that the liquid still contains alkali, and that more acid must be added. In the beginning I generally put one drachm in measure of the diluted acid to the lixivium after every trial with the test paper. This, however, must now be done cautiously, taking care to stir the mixture well after every addition of the acid.

When the effervescence becomes less, and the test paper receives only a slight blue tinge by immersion in the lixivium, the acid should be added still more gradually, and by a very few drops at a time, that no more acid may be employed than is absolutely requisite for the complete saturation of the alkali; which may be known by the cessation of the effervescence, the unchangeable appearance of the test paper on immersion, and the separation of the sulphur which was held in solution by the

alkali, and which separates when the alkali becomes saturated with an acid.

The alkali having been in this way neutralized, the remainder of the acid with its phial is to be weighed again, to ascertain how much of the diluted sulphuric acid has been consumed; and this will show the precise quantity of real alkali which is contained in the sample under examination, when it is known how much acid an alkali in a state of purity is capable of taking up.

In order to provide a scale for calculating this, I took 100 grains of dry potash purified by means of alcohol; and having treated it with the diluted sulphuric acid of the specific gravity of 1.100, I found that it required exactly 520 grains of the acid to saturate it. In like manner I treated pure soda; but 100 grains of this alkali require 812 grains of acid of the same strength for its saturation.

These results being considered as the basis, it is easy, by the rule of proportion, to calculate how much real alkali there is in any sample of kelp, natron, or barilla, by the weight of acid required to saturate it.

But as the two alkalies combine with different portions of acid, the analysis cannot be accurate unless it be ascertained whether the alkali in the sample be soda only, or a mixture of soda and potash; and, if it be of the latter kind, in what relative proportions these alkalies exist.

The most useful test in this case is the liquid muriate of platinum, made by dissolving the crystals of that salt in pure water; for, if a drop of this reagent be added to a small quantity of any alkaline solution, a yellow precipitate, which is a triple compound of potash, oxide of platinum and muriatic acid, will appear if the alkali contain potash; whereas, if it be a solution of soda only, no precipitate will occur. If the alkali under examination should contain *muriate of potash*, (which, however, very rarely occurs,) this would likewise produce a precipitate, and might occasion deception; for the muriate of platinum detects all the *salts* of potash as well as *pure* potash. Should a sample be suspected to contain this salt, a small portion of the lixivium might be supersaturated with sulphuric acid, by which means the muriatic acid would be driven off and easily detected by its peculiar smell, or by presenting ammoniacal gas; and the potash, in the form of sulphate, would be separated by its crystallizing before the sulphate of soda.

There are several other methods by which the fixed alkalies may be distinguished from each other. These are all described in *The Chemical Catechism*, twelfth edition, page 127, &c. The use of muriate of platinum has often been stated to be a new method of detecting potash; but in justice to the memory of

Margraff it ought to be known, that he pointed it out for this especial purpose more than seventy years ago¹.

SODA in its pure state is very similar in the causticity of taste to potash; though in its usual condition it does not so readily absorb water from the atmosphere; on the contrary, its crystals effloresce, and entirely lose their water of crystallization by such exposure. If, however, pure soda be rendered very dry and then moistened with water, it will absorb the water with avidity, and heat will be given out during this absorption, owing to the water becoming actually solidified by the alkali.

Although soda is so analogous to potash in many of its habitudes, that it can only on certain occasions be distinguished by chemical tests, yet the action of these two alkalies in some manufactures, and the combinations they form, are so dissimilar, that we are under the necessity of considering them to be perfectly distinct bodies.

The most remarkable difference in the effects of these alkalies, when employed in manufacturing processes, is in the articles of soap and glass. In that of glass, the mineral alkali more easily combines with the silica; consequently the frit is formed with greater facility and certainty. Soda also produces a glass of greater hardness.

In the manufacture of common hard soap, soda is an essential ingredient. Pure potash will also combine with oil or tallow, and form a complete soap; and it is by this alkali that all the *soft* soap is made which is prepared in Great Britain. But if more than a certain proportion of potash be used in the manufacture of *hard* soap, although the soap might have sufficient consistence, and appear perfectly good when finished, its character would be entirely changed the first day of its exposure to the action of the air in damp weather; for it would then become soft and unsaleable. Great losses were formerly sustained by many manufacturers of soap, from their ignorance of this circumstance. However, if this imperfect soap be dissolved in hot water, and brought to a boiling heat, and while boiling a sufficient portion of common salt be added, the moment these substances come in contact with each other, the potash will quit the tallow to unite with the muriatic acid of the salt, and the soda will then supply its place, and combine with the tallow, so as to form a hard, firm and saleable soap.

Having already given some account of the salts of potash, it will now be proper to notice the principal salts which have been

¹ See Macquer's *Chemical Dictionary*, article *Alkali*.

formed by means of soda. These may frequently be known from the former by their greater degree of solubility in water, and by their containing much water of crystallization, though to this there are some exceptions. They may also be distinguished from the salts of potash by their yielding no precipitate when treated with tartaric acid, or with a solution of muriate of platinum.

Acetate of soda.—This salt was known in the old pharmacopœias by the name of *crystallized foliated earth*. It crystallizes in prisms similar to sulphate of soda; but these cannot be obtained unless the solution contains an excess of soda. It consists of 32 soda + 50 acetic acid.

Arseniate of soda.—This salt differs from arseniate of potash, inasmuch as it crystallizes in six-sided prisms; whereas the latter is incapable of crystallization. If there be, however, an excess of acid in the solution, the arseniate of soda will not crystallize.

Arsenite of soda.—This, like the arsenite of potash, is incapable of crystallization, being a thick yellow liquid, with an odour that is peculiarly nauseous. This salt is decomposable by heat, and the arsenious acid escapes in vapour. It is a compound of arsenious acid 54, and soda 32.

Benzoate of soda.—Unlike its correspondent salt of potash, which is deliquescent, this salt effloresces in the atmosphere, but its taste is similar, and it is also very soluble in water. The crystals likewise are considerably larger than the crystals of benzoate of potash.

Bicarbonate of soda.—This, like the bicarbonate of potash, may be prepared by passing a stream of carbonic acid gas into a saturated solution of the soda of commerce, when it precipitates in small crystals, as it requires much more water for its solution than the carbonate. If the bicarbonate of soda be exposed to a red-heat, it will lose exactly one-half of its carbonic acid, and thereby be reduced to common carbonate. It may be observed, that this salt is found native in some parts of Africa in considerable quantities, and has been imported into this country, and sold under the name of *trona*. There is a process in the London Pharmacopœia for preparing this bicarbonate, by treating the carbonate of soda with carbonate of ammonia, which see.

Borate of soda is readily formed by saturating common borax with the boracic acid; borax itself being a sub-borate of soda. According to Bergman, two pounds of borax will require one pound of boracic acid for its saturation.

Camphorate of soda is similar to camphorate of potash in most of its properties, and may be formed in the same manner. Its crystals are in irregular forms, but they may be obtained very white and transparent. If submitted to heat, the acid burns

with a beautiful blue flame at the first, and afterwards with one of a purple hue.

Carbonate of soda.—This salt, which is employed in large quantities in the manufactures of the country, is usually produced from four distinct sources, viz. from the barilla of Spain and Sicily, from the kelp which is made on our own shores, from a native production which is brought from Egypt under the name of natron, and now, perhaps in larger quantities than either, from the decomposition of sulphate of soda, the residuum which is left in the pots after the distillation of muriatic acid from common sea salt. It crystallizes in octohedrons, with a rhombic base, forming a solid with ten faces. The dry salt consists of soda 32, and carbonic acid 22.

The crystallized salt consists of carbonate of soda 54, and 10 waters 90.

Chromate of soda is a crystallizable salt of an orange colour. If a solution of chromate of soda be added to a solution of lead, copper, iron, mercury, or silver, it forms an insoluble precipitate, varying in colour according to the nature of the metallic solution into which it is poured. In the solutions of zinc, tin, and some other metals it forms no precipitate¹.

Citrate of soda.—This salt agrees in several of its properties with citrate of potash. It crystallizes in hexahedral tables, is soluble in two parts of water at 56°, and effloresces when exposed to the air. It consists of citric acid 58, and soda 32.

Fluate of soda is formed by pouring a solution of pure soda into fluoric acid. The salt crystallizes on cooling. It has less taste than fluate of potash, and is not altered, like that salt, by exposure to the air.

Hydrate of soda is a compound of caustic soda and water. Though this alkali be purified as much as possible by lime and alcohol, and afterwards by fusion, it will still contain a portion of water. It consists of 32 soda + 9 water.

Hydrosulphuret of soda crystallizes in four-sided prisms, terminated by quadrangular pyramids. Its taste is intensely bitter, though the crystals are transparent and colourless. It is very soluble in water, and deliquesces in the air, during which process the solution acquires a green colour.

For some account of the formation of this salt, see the article Sulphuret of soda.

Iodate of soda.—This salt has been formed and examined by Gay Lussac. It may be made by dissolving iodine in a solution of pure soda. It forms itself in small prismatic crystals.—*Annales de Chimie*, tome xci.

¹ See John, *Annals of Philosophy*, vol. iv. page 425.

Lactate of soda.—This salt is very similar to lactate of potash. It has been examined by Berzelius, who thinks the two salts can only be distinguished by analysis.

Malate of soda.—This salt is uncrystallizable, very soluble in water, and deliquescent in the atmosphere.

Molybdate of soda agrees with molybdate of potash in many of its properties; but it is more soluble in water, and affords transparent crystals, which are unalterable by exposure to the atmosphere.

Muriate of soda, or chloride of sodium dissolved in water, is one of the most abundant salts in nature. It is the chief ingredient in sea-water, and abounds in salt springs in most parts of the world. When the water is expelled from it, by which means the oxygen is abstracted from the soda, and the hydrogen from the muriatic acid, chloride of sodium is re-obtained, which is found in immense masses in the county of Chester in the form of rock-salt. A valuable paper by Dr. Henry on the various kinds of common salt, will be found in the *Philosophical Transactions* for 1810, page 89, &c.

Chloride of sodium consists of 24 sodium + 36 chlorine; muriate of soda, of 32 soda + 37 muriatic acid, or of water 9, and chloride of sodium 60.

Nitrate of soda is the cubic nitre of the old chemists. It forms itself in rhombic crystals, which require three parts of water at 60° for their solution. It has in a slight degree the property of deliquescence, and is soluble in less than its own weight of water at 212°. It is a compound of soda 32, and nitric acid 54.

Dr. Lewis has treated at length on the nature of this salt¹.

Oxalate of soda is a salt which appears in small crystals like grains of sand. This salt dissolves in cold water with difficulty, but is perfectly soluble in hot water. Its taste is cooling and bitter, and it falls to powder when submitted for some time to a gentle heat. It consists of oxalic acid 36, and soda 32.

Phosphate of soda.—This is the *sal perlatum* of the old chemists. It possesses a very mild saline taste, and on this account was introduced into the practice of medicine by Dr. George Pearson. It consists of soda 32 + phosphoric acid 28, and when crystallized combines with 12 proportionals of water 108 + 60 phosphate of soda = 168.

Phosphite of soda.—The properties of this salt are not much known. The hypophosphite of soda is very soluble both in water and in alcohol, and indeed is more deliquescent even than muriate of lime itself.

Silicate of soda.—This salt may be formed in the same way as silicate of potash, with the substitution of the mineral for the

¹ *Philosophical Commerce of the Arts*, pages 642—646.

vegetable alkali. Glass is a subsilicate, containing a considerable excess either of potash or soda. See the Essay on the Manufacture of Glass.

Subborate of soda is brought from the East Indies in a very impure state, and sold under the name of tincal. Formerly none but the Dutch were capable of purifying it; but now this is well done both in France and in England, and when purified is called borax. The crystals are irregular hexangular prisms, which are slightly efflorescent. These, according to Bergman, are composed of boracic acid 34, soda 17, and water 49.

Boracic acid is usually procured from this salt by the affusion of sulphuric acid; but its chief consumption is as a flux, and by the braziers for solder.

Suberate of soda.—This salt differs from the suberate of potash chiefly in the circumstance of its being incapable of crystallization; whereas suberate of potash crystallizes in prisms. The best account we have of these salts will be found in a copious extract, in the *Annales de Chimie*, tome xxiii. pages 42—62, from a memoir on cork, and on the combinations of its acid, read to the Institute of Paris by Bouillon La Grange.

Succinate of soda.—This salt differs in several respects from succinate of potash. It crystallizes in hard transparent four-sided and hexagonal prisms, which are unchangeable in the air; whereas the succinate of potash is extremely soluble, is crystallized with difficulty, and the salt, which is in the form of very small prisms, readily deliquesces in the atmosphere.

Sulphate of soda.—This is the *sal mirabile* of the old chemists, and has been long known in this country under the name of *Glauber's salt*. It usually crystallizes in large four-sided prisms, hard and transparent; but they effloresce when exposed long to the atmosphere, and fall into powder. Sulphate of soda is produced in considerable quantities by the makers of muriatic acid. It is composed of sulphuric acid 40, and soda 32, and when crystallized it consists of dry sulphate of soda 72, and water 90.

Sulphite of soda.—This is a crystallizable salt, not quite so soluble as the sulphate of soda. It consists of sulphurous acid 32, and soda 32.

The crystals are composed of one proportional of the salt, and eight proportionals of water.

Sulphuret of soda.—When sulphur and soda are fused together, a red compound is formed, whose taste is bitter and otherwise disagreeable. This is sulphuret of soda. For an account of its nature and properties, see Vauquelin, *Annales de Chimie*, tome xli. page 190. When this sulphuret, which is very deliquescent, is dissolved in water, it produces a yellow solution of hydrosulphuret of soda.

Supertartrate of soda is readily obtained by adding tartaric acid to a solution of tartrate of soda. Thenard has treated upon this salt. See *Annales de Chimie*, tome xxviii. page 12.

Tartrate of soda.—This salt may be formed by the direct union of tartaric acid and soda. It is composed of tartaric acid 67, and soda 32.

It crystallizes in needle-formed crystals, which are much more soluble in water than the tartrate of potash.

Tungstate of soda.—This salt differs much from the tungstate of potash already described, as it crystallizes in solid elongated hexahedral tables; whereas the latter is incapable of crystallization, and, when concentrated as much as possible, deliquesces by exposure to a damp atmosphere. Tungstate of soda, which may be prepared by dissolving tungstic acid in a solution of soda, is soluble in four parts of cold, or two parts of boiling water. Vauquelin and Hecht have investigated the nature of the salts formed with tungstic acid¹.

Urate of soda.—This salt is in the form of a white powder, having, according to Dr. Thomson, the same appearance as pure uric acid². It is soluble in a lye of caustic soda.

It had for many years been usual to consider the fixed alkalies to be simple undecomposable bodies; but when the present modes of chemical analysis were adopted, it was soon suspected that soda and potash would ultimately be found to be compound substances. Morveau had long ago published an opinion that the fixed alkalies were not simple substances; and in the first edition of *The Chemical Catechism*, printed in the year 1806, I fully expressed my opinion of the compound nature of these bodies. In the year 1807 a very important paper was read by Sir H. Davy before the Royal Society, on the agencies of galvanism in the decomposition of a variety of alkaline and earthy salts. The experiments which he detailed in that paper were sufficient to produce an alteration in all our former ideas of chemical affinity, as they proved decisively that the formation of all chemical compounds may depend on the electrical state of the materials of which they are composed. Soon afterwards, by means of the large galvanic apparatus at the Royal Institution, he was enabled to decompose the fixed alkalies, and to exhibit their metallic bases in an insulated and separate state.

It was on the 19th day of November, in the year 1809, that Sir Humphry Davy, in a paper read before the Royal Society,

¹ *Journal des Mines*, No. xix. page 80.

² *System of Chemistry*, vol. ii. page 454.

announced that he had succeeded in his attempts to decompose these bodies.—In his first attempts for the decomposition of the fixed alkalies, he entirely failed, in consequence of his having acted upon their aqueous solutions. He afterwards used potash in the state of igneous fusion, and acted upon it by an electrical power, which was produced from a galvanic battery of 100 plates, of 6 inches square, highly charged.

Here some brilliant phenomena were produced. A most intense light and a column of flame were exhibited, which seemed to be owing to the development of combustible matter; and when the order was changed, so that the alkali was brought in contact with the negative side of the battery, aëriform globules, which inflamed in the atmosphere, rose through the potash. Being, however, unable to collect the products of decomposition by this means, he had then recourse to pure potash in its usual state, and depended on electricity alone for its fusion as well as its decomposition.

A small piece of pure potash, moistened a little by the breath, was placed upon an insulated disc of platinum, connected with the negative side of a battery consisting of 100 plates of 6 inches and 150 of 4 inches square, in a state of intense activity, and a platinum wire, communicating with the positive side, was brought in contact with the upper surface of the alkali. Under these circumstances a vivid action soon commenced. The potash began to fuse at both its points of electrization, and small globules having a high metallic lustre, and precisely similar in visible characters to quicksilver, appeared, some of which burnt with explosion and bright flame. These globules, which appear to be metallic, are the basis of potash, that alkali being composed of this peculiar base and oxygen.

Soda, when acted upon in the same manner, exhibited an analogous result, and these effects equally took place in the atmosphere, and when the alkali was acted upon in the vacuum of an exhausted receiver: but these globules could not in either case be produced from *crystallized* alkalies.

When a globule of the base of potash was exposed to the atmosphere, it immediately attracted oxygen, and a white crust formed upon it, which proved to be pure potash. When the globules were strongly heated and then suspended in oxygen gas, a rapid combustion with a brilliant white flame was produced, and these metallic globules were converted to an alkali, whose weight greatly exceeded that of the combustible matter consumed.

When Sir H. Davy had thus detected the bases of the fixed alkalies, he had considerable difficulty to preserve and confine them, so as to examine their properties and submit them to ex-

periments. He found, however, that in recently distilled naphtha they may be preserved many days, and that their physical properties may be easily examined in the atmosphere when they are covered by a thin film of it.

The basis of potash at 60° Fahrenheit is only imperfectly fluid; at 70° it becomes more fluid; and at 150° its fluidity is perfect, so that different globules may be easily made to run into one. At 50° it becomes a soft and malleable solid, which has the lustre of polished silver; and at about the freezing point of water it becomes harder and brittle, and when broken in fragments exhibits a crystalline texture of perfect whiteness and high metallic splendour.

To be converted into vapour, it requires a temperature approaching that of a red-heat. It is an excellent conductor of heat, and a perfect conductor of electricity.

Resembling the metals in all these properties, it is, however, remarkably different from most of them in specific gravity; for it will not sink in double-distilled naphtha, whose specific gravity is only .770, that of water being considered as 1.000. Sir H. Davy has determined by experiment that its specific gravity is to that of mercury as 10 to 223, which gives a proportion to that of water nearly as 6 to 10; so that it is the lightest metallic body known. When this substance is introduced into chlorine gas, it burns spontaneously with a bright red light, and chloride of potash is formed. When thrown upon water, it decomposes it with great violence, and instantaneous explosion is produced with brilliant flame, and a solution of pure potash is the result. When a globule is placed upon ice, not even the solid form of the two substances can prevent their union; for it instantly burns with a bright flame, and a deep hole is made in the ice, which is found to contain a solution of potash. When a globule is dropped upon moistened turmeric paper, it instantly burns, and moves rapidly upon the paper, as if in search of moisture, leaving behind it a deep reddish brown trace.

So strong is the attraction of the basis of potash for oxygen, that it discovers and decomposes the small quantities of water contained in alcohol and ether, even when they are carefully purified. When thrown into the mineral acids, it inflames and burns on the surface. In sulphuric acid, sulphate of potash is formed; in nitric acid, nitrous gas is disengaged, and nitrate of potash formed. When brought in contact with a piece of phosphorus, and pressed upon, there is a considerable action; they become fluid together, burn, and produce phosphate of potash. When a globule is made to touch a globule of mercury about twice as large, they combine with considerable heat: the compound is fluid at the temperature of its formation; but when cool it

appears as a solid metal, similar in colour to silver. If this compound be exposed to air, it rapidly absorbs oxygen; potash which deliquesces is formed; and in a few minutes the mercury is found pure and unaltered. When a globule of the amalgam is thrown into water, it rapidly decomposes it with a hissing noise, potash is formed, hydrogen disengaged, and the mercury remains free. The basis of potash readily reduces metallic oxides when heated in contact with them. It decomposes common glass by a gentle heat, and at a red heat effects a change even in the purest glass.

In his experiments on soda, Sir H. Davy has discovered that its base, like that of potash, is white, opaque, and has the lustre of silver. The property of welding, which belongs to iron and platinum, at a white heat only, is possessed by this substance at common temperatures. It is very similar in its more obvious properties to the base of potash; but it has greater specific gravity, being to that of water nearly as nine to ten, or as .9348 to 10.000. In oxygen gas it produces a white flame, and sends forth bright sparks, occasioning a very beautiful effect. In chlorine gas it burns vividly, with numerous scintillations of a bright red colour. In the quantity of one-fortieth, it renders mercury a fixed solid, of the colour of silver, and forms an alloy with tin. When amalgamated with mercury, the amalgam will combine with other metals. Sir H. Davy tried this with iron and platinum, and had reason to believe that these latter metals remain in combination with the mercury, even when deprived of the new substance by exposure to the air.

The whole of the sixth chapter of this very interesting paper is occupied with the detail of several curious and ingenious experiments to ascertain the proportions of the bases and oxygen in the two fixed alkalies; from whence he concludes that potash may be considered as consisting of about 5 parts basis, and 1 of oxygen; and soda of 3 basis, and 1 oxygen.

In reply to the question, whether the bases of potash and soda should be called metals, it might be said that they agree with metals in opacity, lustre, malleability, conducting powers as to heat and electricity, and in their qualities of chemical combination. Even their low specific gravity does not appear a sufficient reason for making them a new class; for amongst the metals themselves there are remarkable differences in this respect, platinum being nearly four times as heavy as tellurium; and tellurium is not much more than six times as heavy as the basis of soda. Conceiving the basis of the two fixed alkalies to be metals, Sir H. Davy has named one Potassium, and the other Sodium, adopting that termination which, by common consent, has been applied to other newly discovered metals.

In concluding this very important communication, Sir H. Davy remarks that an immense variety of objects of research

is presented in the powers and affinities of the new metals produced from the alkalies. In themselves they will undoubtedly prove powerful agents for analysis; and, having an affinity for oxygen stronger than any other known substances, they may possibly supersede the application of electricity to some of the undecomposed bodies.

In sciences kindred to chemistry, the knowledge of the nature of the alkalies, and the analogies arising in consequence, will open many new views; they may lead to the solution of many problems in geology, and show that agents may have operated in the formation of rocks and earths which have not hitherto been suspected to exist.

With respect to the properties of potassium, it may be said, in addition to those already detailed, that it is ductile and of the consistence of soft wax; and, though originally of great lustre, it immediately loses its brilliancy by exposure to the air. At a temperature higher than that at which water congeals, it is a hard and brittle substance; and at a red heat becomes dissipated in vapour. But it is, perhaps, one of the most curious properties of these metalloids, that if an alloy be formed, composed of one part of potassium and three of sodium, the compound will continue fluid at the low temperature of 32° .

Since the first edition of these Essays was published, a new fixed alkali called *lithia* has been discovered in the petalite, a mineral brought from the mine of Utoen in Sweden. This discovery was made by M. Arfvedson, a young Swedish chemist. The mineral called *spodumene* also affords the same substance, and it has likewise been found in crystallized *lepidolite*.

When *lithia* is submitted to the action of the voltaic pile, it becomes decomposed; and, similar to potash and soda, a metallic substance of great brilliancy and highly combustible is separated from it. Hence it appears that lithia, like the other fixed alkalies, is a metallic oxide, and from hence its metallic base is called *lithium*.

During the first analysis of the petalite, M. Arfvedson supposed its alkali to be soda; but he soon found that it differed from that alkali, and that it may be distinguished both from potash and soda by its power of neutralizing a much larger quantity of any acid.

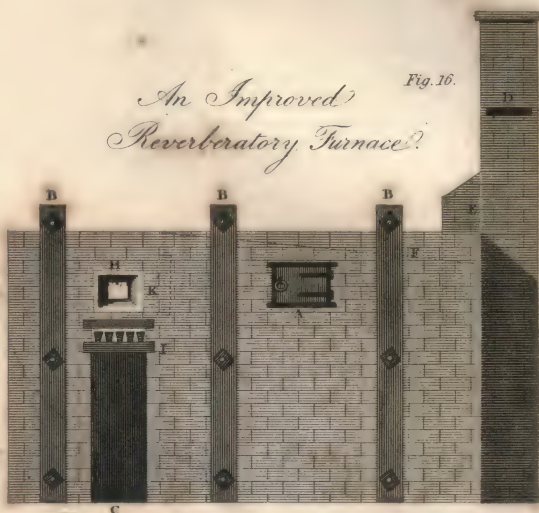
Like the other alkalies, lithia is very soluble in water; and its solution, like theirs, possesses an acrid and nauseous taste. According to Vauquelin, lithia attracts carbonic acid from the atmosphere with great avidity, and in neutralizing the acids is more powerful even than magnesia. It consists of lithium 10, and oxygen 8.

Several compounds have already been formed by the artificial combination of this new alkali with the acids, the chief of which



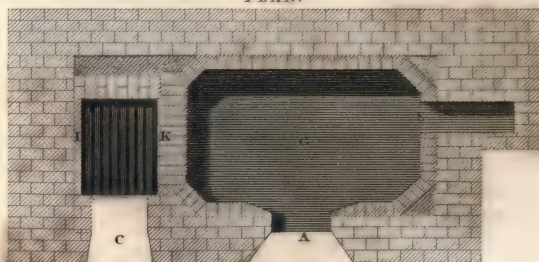
*An Improved
Reverberatory Furnace.*

Fig. 16.



PLAN.

Fig. 17.



- | | |
|----------------------------|-------------------------------|
| A. Door of Furnace..... | F. Height of the arch..... |
| B. Three Iron bands..... | G. Floor of the oven..... |
| C. Ash pit..... | H. Fire place & Hopper..... |
| D. Damper in chimney..... | I. Fire bars..... |
| E. Passage to chimney..... | K. Bridge of the furnace..... |

are the chloride, the iodide, and the sulphuret of lithium; and the sulphate, the nitrate, the muriate, the phosphate, and the carbonate of lithia. Of these, the sulphate of lithia crystallizes in small prisms of a shining white colour. It is more fusible and soluble than sulphate of potash, and, unlike that salt, its taste is not bitter, but merely saline. The muriate and nitrate of lithia are both deliquescent salts; while the carbonate is efflorescent and sparingly soluble in water.

Lithia, like the other fixed alkalies, has the property of converting the vegetable blues to a green, and of turning the vegetable yellows brown. It is very sparingly soluble in alcohol.

In speaking of the fixed alkalies in connexion with the trade of the country, I might have observed that the supplies of soda to be derived from the decomposition of common salt are inexhaustible.

The rocks of salt in the British Islands are far from inconsiderable; but the many thousands of tons of it which are continually washing our shores will furnish a most plentiful supply for every purpose whatever, whether for manufacture, agriculture¹, or any other branch of the arts: especially now that its decomposition is so generally understood and practised, and the abolition of the duty upon it has rendered it so cheap. Most of the large soap makers now manufacture soda for their own use, which they call English Barilla.

I ought here to state that for twenty years Mr. Parkes was indefatigable in his efforts to obtain the abolition of the duties on salt. For a long time he could get little attention paid to the subject; but by that incessant perseverance which characterized all his actions, he succeeded in calling the attention of the public towards it; and had the pleasure of receiving the congratulations of the members of the house of commons who had warmly interested themselves in the measure, when it was at last carried almost by acclamation. His most sanguine predictions have since been verified; even in London the price has fallen from 35*l.* per ton to 2*l.* 10*s.*; and the quantity used for agricultural and manufacturing purposes has far exceeded even his anticipations.

¹ Sea salt is perhaps of still more importance to the grazier than to the mere agriculturist, which is shown by the fattening quality of our salt marshes, and by the avidity with which all Neat Cattle devour their food when sprinkled with salt. See *A Letter to the Farmers and Graziers of Great Britain, on the advantages of using Salt in the various branches of agriculture, and in feeding all kinds of farming stock; with a large Appendix of Proofs and Illustrations.* By the author of these Essays. The fourth edition, price 2*s.*

ESSAY X.

ON EARTHENWARE AND PORCELAIN.

THE origin of Earthenware and Porcelain may probably be ascribed to accident. It is very possible that the peculiar changes which clay experiences on being burnt in the fire, may have afforded to some of the early inhabitants of the world the first hints for applying this earth to a variety of useful purposes.

When mankind had no shelter from the dews of the night, or the burning sun of noon-day, but what could be derived from the trees of the forest, how anxious must they have been to improve their condition, and how solicitous to discover some mode of fortifying their miserable huts against the vicissitude of the seasons ! It is therefore not unlikely that baked clay in the form of bricks was made use of for this important purpose in an early stage of society. This application of it is indeed known to have been very ancient. The celebrated Tower of Babel, 2200 years before Christ, was built with bricks¹; and when the Israelites sojourned in Egypt 600 years afterwards, their task-masters employed them chiefly in this kind of manufactory². Bricks of clay were used also by other nations of antiquity. The Romans in particular had acquired great skill in the method of making, and also in the manner of burning, their bricks. This will appear by a comparison of the bricks that compose any of their edifices, with those of the present day. The Roman wall at St. Alban's (the ancient city of Verulam) is a direct proof of this assertion³.

It was probably not long after the employment of clay in making bricks, that mankind learnt the art of using it in various other ways, and acquired methods of moulding it into vessels of capacity, and utensils for culinary purposes. Accordingly the

¹ "And they said one to another, Let us make bricks, and burn them thoroughly." *Genesis* xi. 3, 4.

² *Exodus*, chap. i. verses 13, 14. See also chap. v. verses 6—19.

³ See Mr. J. Webster's Letter to Bishop Littleton, on this subject, in the 2d vol. of the *Archæologia*, page 184. See also some observations on the Ruins of a Roman wall at York, by Martin Lister, Esq. in the *Phil. Transactions*, vol. xiii. p. 238. The bricks in this wall were 17 inches long, 11 inches broad, and 2½ inches thick, and they were all extremely hard.

most ancient writers we have, mention earthen vessels⁴, and they speak of them as if they had been in use from time immemorial. It appears also that considerable pains were taken in tempering the clay for these purposes, for we read that this process was performed by treading it with the naked feet⁵.

In the fifth volume of the *Archæologia* is an account of two vases, of great antiquity, which were found on the Mosquito shore in South America, and which are now in the possession of Lord Hillsborough. The account of them is transmitted by Governor Pownal, who says, "It is a decided fact that they were made in South America, and that they are curious exemplars of some of the first efforts of human ingenuity, and remains of what are become antiquities even among the Indians." He also says that remains of ancient potteries have been discovered high up the Black River, on the Mosquito coast, and that Father D. Acuña mentions, that some of the Indians on the river of the Amazons had carried this ancient manufactory to a great extent, so as even to establish a traffic for it with the neighbouring nations⁶.

From a variety of testimonies we learn that the Greeks very early acquired proficiency in the arts of pottery. Mr. Fordyce, in describing the theatre of Herculaneum, has told us, that they had contrived how to form earthen vessels which had the property of increasing the voices of their actors⁷.

According to Herodotus, however, vessels of earthenware were in his time extremely scarce, and highly esteemed by the nations around them. "Twice in every year," says he, "there are exported from different parts of Greece to Egypt, and from Phœnicia in particular, wine secured in earthen jars, not one of which jars is afterwards to be seen; for the principal magistrate of every town is obliged to collect all that are imported to the place where he resides, and send them to Memphis. The Memphians fill them with water, and afterwards transport them to the Syrian deserts. Thus all the earthen vessels carried into Egypt, and there carefully collected, are continually added to those already in Syria⁸."

According to Vitruvius, who wrote in the time of Augustus Cæsar, the ancient Romans made their water-pipes of potter's clay. These were generally two inches thick, and joined together with common mortar mixed up with oil. When they had a joint to make, they employed also a piece of free-stone, which they pierced through to receive the two ends of the pipes to strengthen

⁴ "But the earthen vessel wherein it is sodden shall be broken." *Levit.* vi. 28.

⁵ "And he shall come upon princes as upon mortar, and as the potter treadeth clay." *Isaiah* xli. 25.

⁶ *Archæologia*, vol. v. p. 318.

⁷ *Memoirs concerning Herculaneum*, by W. Fordyce, M.A. London, 8vo, 1750, p. 16.

⁸ Beloe's *Herodotus*, book iii. s. 6.

and secure them in the manner of a bandage. Some of these pipes were taken up a few years ago in Hyde Park¹.

The people of Britain in ancient times were furnished with earthen vessels by the Phœnicians; and they no doubt soon learnt to make others in imitation of them. Many urns of earthenware, supposed to have been the workmanship of the ancient Britons, have been found in barrows in different parts of this kingdom. It is also well known that the Romans made use of earthenware, and that they greatly excelled in the art of making it², as well as in the manufacture of bricks and tiles. Vestiges of several of their great potteries are still discernible in many parts of this island.

There is reason to believe that there was once a considerable manufactory of Roman earthenware on a small island which 2000 years ago stood in the mouth of the Thames, at the back of Margate Sand, now known by the name of the Queen's Channel, at about two leagues from the coast. Governor Pownal, who has written a memoir on this subject, says that fishermen have occasionally, for many years, taken up with their nets complete pieces of earthenware from this particular spot. They are all of coarse workmanship; but he supposes that this was a manufactory specially employed in making earthen vessels to be used according to the Roman ritual in their religious ceremonies. Each vessel has Atilianus, the name of the maker, neatly impressed upon it³.

It is probable that the early inhabitants of the world arrived nearer to perfection in the modelling of clay, and in the making of earthen wares, than in the management of any other manufactures; for in the kingdoms of China and Japan⁴, not only common earthenware, but even porcelain of very excellent quality, was made long before the commencement of the Christian æra.

"First China's sons, with early art elate,
Form'd the gay tea-pot and the pictured plate;
Saw with illumined brow and dazzled eyes
In the red stove vitrescent colours rise⁵;

¹ Switzer's *Hydrostatics*, 4to, 1729, p. 116.

² In the *Philosophical Transactions*, vol. xv. page 1017, is an account of a fine Roman earthen vessel found near York, with the figure of a female face upon it, of the natural size. It was sent to the Ashmolean Museum in Oxford.

³ *Archæologia*, vol. v. page 282, &c.

⁴ This manufacture is still of great importance in China. At present "there are five hundred furnaces at work, and nearly a million of men employed, at King-to-Ching, a province of Kian-si." Chaptal's *Elements of Chemistry*, 8vo, 1791, vol. ii. page 94.

⁵ "No colour is distinguishable in the red-hot kiln of the potter, but the red itself, till the workman introduces a small piece of dry wood; which by producing a white flame renders all the other colours visible in a moment."

DARWIN.

Speck'd her tall beakers with enamell'd stars,
 Her monster-josses and gigantic jars;
 Smear'd her huge dragons with metallic hues,
 With golden purples, and cobaltic blues;
 Bade on wide hills her porcelain castles glare⁶,
 And glazed pagodas tremble in the air."

It appears also that porcelain, as well as earthenware, was made in ancient Egypt; for several small earthen figures are frequently found deposited with the Egyptian mummies, resembling them in shape, and covered with a blue glazing similar to that of the Chinese porcelain. Du Halde has said that lapis lazuli abounds in Egypt, and hence some have supposed that this blue has been produced by ultramarine. This, however, could not have been the case, as it is now well known that any colour made from lapis lazuli would instantly be destroyed by the intense heat of a potter's oven⁷.

Anxious to ascertain what article could have been employed to produce so beautiful a colour in such early times, Mr. Delaval broke off a piece of the blue enamel from one of these small images, and submitted it to a variety of experiments and to the action of several chemical tests. In all these cases, the results were exactly what he would have expected had he operated on a piece of modern enamel which had been coloured with the blue oxide of cobalt⁸; the very article which the potters of the present day employ. What an idea does this give of the attainments of the Egyptians, more than two thousand years before the science of chemistry had made any progress in Europe!

That porcelain was not uncommon in Europe during the first century of the Christian æra, is evident from the discoveries that were made in the excavations of those cities which were destroyed by the eruption of Vesuvius in the first year of the reign of the emperor Titus. For, according to the catalogue made by Bayardi, there were no less than 193 vases and other utensils of earthenware and porcelain taken out of the ruins of Herculaneum⁹.

We are not however to suppose that these porcelain vessels were of European manufacture; for we are expressly informed that the first porcelain which was seen at Rome was brought

⁶ This refers to the porcelain buildings of the Chinese. An account of a very singular one will be found in the *Chemical Catechism*, twelfth edition page 103.

⁷ See Klaproth, *Annales de Chimie*, xxi. p. 150, and Guyton on the colouring Principle of the Lapis Lazuli, in the xxxivth vol. of the *Annales de Chimie*, p. 58; also, in Nicholson's *Journal*, 4to, vol. i. p. 77, and vol. iv. p. 311.

⁸ See "*An Experimental Inquiry into the Cause of the Changes of Colours in Opaque and Coloured Bodies.*" By Edward Hussey Delaval, 4to, London, 1777.

⁹ See the 1st vol. of Martyn and Lettice's *History of the Antiquities of Herculaneum*.

thither from Pontus in Asia by the victorious army of Pompey, and that this was only sixty-four years before Christ¹.

This in some measure accounts for the great excellence which the Persians have arrived at in this elegant art. Sir John Chardin, who travelled through Persia about the middle of the 17th century, has taken notice of their beautiful porcelain, and quotes a passage from Propertius, one of the writers of the Augustan age, to show the antiquity of the art among that people².

The Etruscans, who were probably a colony from Phœnicia, are noted by the early writers for their excellence in the manufacture of porcelain. Dr. Darwin, who was intimately acquainted with the great Mr. Wedgwood, and knew all his sources of information, supposes that their principal manufactories were about Nola, at the foot of Vesuvius, and that they learnt the art from the Chinese. This elegant writer has thus given his testimony to the superiority of their productions :

“ETRURIA ! next beneath thy magic hands
Glides the quick wheel, the plastic clay expands :
Nerved with fine touch, thy fingers (as it turns)
Mark the nice bounds of vases, ewers, and urns ;
Round each fair form in lines immortal trace
Uncopied Beauty and ideal Grace.”

The art of painting vases in the manner of the Etruscans has been lost for ages, and this is supposed, by the author of the *Dissertations* on Sir William Hamilton's Museum, to have happened in the time of Pliny. The honour of the recovery of this long-lost art does not however belong to the late Mr. Wedgwood, as has been asserted ; for though he was the first to imitate the correct and beautiful forms of the Etruscan vases and the paintings upon them, his vases were painted by a different process from that which was employed on the urns, &c. of the ancients.

Mr. Harmer informs us that the best Asiatic porcelain is manufactured at Skiraz, the capital of that province, which is distinguished from the other provinces of that country by the name of Persia properly so called ; also at Metched, the capital of Bactriana ; at Yesd, and at Kirman, in Caramania ; and in particular in a town of Caramania called Zorendi. The earth of which these vessels are made is a pure enamel within, as well as without, like that of the Chinese porcelain ; its grain is as fine, and it is as transparent ; so that it frequently equals and sometimes even excells that of the Chinese, its varnish is so exquisite.

The Persian porcelain has another excellence, that it resists

¹ Pliny, l. xxxvii. § 2.

² Sir John Chardin's *Travels in Persia*, folio, London, 1686.

fire, so as not only to allow of water being boiled in it, but the vessels for the express purpose of boiling are made of it. It is so hard, that it is employed in making mortars for grinding colours and for pounding other things, and also for the moulds for making bullets. The materials of which this beautiful porcelain is made are glass and the small pebbles found in rivers, ground very fine; with a slight mixture of argillaceous earth.

It is said that the potters of the city of Yesd, in Caramania, already mentioned, sent one day to the potters of Ispahan, as it were in defiance, a porcelain vessel, which would hold six English quarts of water, and yet weighed only the eighth part of an ounce. Harmer's *Observ.* vol. i. page 75.

In connexion with this account of the excellence of the Persian porcelain, it is related that in the year 1666 an ambassador of the Dutch East India Company having brought many rich presents for the Persian court, and being ignorant of the value which this people set upon their own manufacture, brought, among other articles, fifty-six pieces of old China porcelain; and that the king when he saw them laughed heartily in derision, asking with an air of contempt what they were. The Dutch merchants frequently mix this Persian porcelain with that of China in what they send to Holland for the supply of that market.

The Barbarini or Portland vase, has sometimes been adduced as a proof that the ancients had arrived at great excellence in the manufacture of porcelain. This beautiful piece of antiquity was discovered in the tomb of Alexander Severus, who died so early as the year 235, and the late duchess of Portland actually paid a thousand guineas for it. But, unfortunately for such a speculation, this exquisite piece of workmanship is not made of porcelain, but of glass.

A thick coat of white semi-transparent glass covers the whole of this urn, which is itself made of a deep blue glass, and the white covering appears to have been cut by the lapidary in the same way as the subjects of antique cameos on coloured grounds. Siracides relates that the ancients had also the art of covering *earthen* vessels with a crust of glass. Mr. Wedgwood's imitation of this elegant piece of antiquity is however of *porcelain*, and deserves every commendation that can be bestowed upon it. The history of this production may be given in a few words.

Several of the nobility and gentry being desirous of having a copy of this beautiful piece of antiquity, they engaged Mr. Wedgwood to endeavour to imitate it; and he actually produced a vase which for elegance and beauty was considered to be fully equal to the original. The subscription was for fifty vases at 50*l.* each; and, notwithstanding the large sum to which this subscription amounted, such heavy expenses were incurred in their fabrication,

that Mr. Byerley, the partner of Mr. Wedgwood, has assured me that they lost money by the undertaking. Mr. Webber the artist received five hundred guineas for modelling it.

In attempting the history of the manufacture of European porcelain, it may be remarked, that although porcelain had been brought into this quarter of the world before Christ, as has been mentioned above, there is reason to believe that the introduction of the knowledge of making porcelain in Europe was but of late years, as will be seen in the sequel. Porcelain is not made even now in the Indies; what is consumed there is all imported either from Persia, Japan, or China, and the other kingdoms between China and Pegu.

The English cannot, I presume, lay claim to much excellence in their manufacture of earthenware before the time of the late Mr. Wedgwood, who began his indefatigable researches about the year 1750: for in the beginning of the last century, all the best tiles and even the finer sort of bricks were imported from Denmark, Germany, and Holland. Not but that bricks and tiles of clay had long been made amongst us; for there is an act of parliament now on the statute books, that was passed in the 17th year of the reign of Edward IV., which directs the time for digging the earth, the manner of making the bricks, &c.; and it is so expressed, that we have reason to conclude that bricks had been made in England from time immemorial. While on this article, I am desirous of mentioning that there is a paper on the process of burning bricks, in the third volume of Bergman's Chemical Essays, and that it contains many hints which may be useful to those who are engaged in that occupation.

It seems strange that our remote ancestors did not arrive at greater perfection in the manufacture of all these articles, when it is considered that the island produces not only a great variety of clays, but also all the other materials necessary for the production of the best earthenware and porcelain: Dr. Martin Lister, who wrote in the latter part of the seventeenth century, distinguishes no less than two-and-twenty different sorts of clay in Britain which fell under his own observation. Moreover, the exquisite pieces of workmanship which were produced at different periods by the English sculptors, show that there was no deficiency of genius and skill among our artists, who probably conceived that the working in clay was beneath their attention.

In returning from this digression, I have to observe, that the common stoneware, and that called white enamel, have been made in various countries of Europe ever since the fifteenth century. The former of these is distinguished by a glaze made by means of muriate of soda; the latter is covered with a real

glass, rendered opaque by the white oxide of tin¹. Stoneware is the only article of pottery that can be employed for chemical purposes, where a great heat is required. Macquer says that our best common stoneware is the most perfect pottery that can be, and that it has all the essential qualities of the finest old Japanese porcelain. Mr. Pott, the author of *Lithogeognosia*, has written a treatise expressly to explain the requisite perfections of stoneware for the purpose of chemical vessels; but I conceive that what is made at Lambeth near London by the best of those manufacturers, is susceptible of but little improvement. For boiling syrups, and for many other culinary purposes, the Lambeth stoneware is the best article that can possibly be employed; as it is cheap, will stand a great heat, and is perfectly wholesome; whereas many of the earthen utensils used in our kitchens are glazed with lead, and consequently are extremely dangerous. Several years ago, I adverted to this subject in another work; but I was desirous of repeating the admonition now, because I consider the health of the community must be impaired by the frequent use of earthen vessels which are covered with the common Staffordshire glaze. The acetic acid will readily dissolve the oxide of lead; hence the boiling of pickles, and the making of other culinary preparations in such vessels, must be highly improper.

The white enamel ware was brought to its present state of perfection by Bernard de Palissy, a native of the diocese of Agen, in the province of Guienne in France; a spot celebrated for being the birth-place of the memorable Joseph Scaliger.

Palissy was in a low station of life; but he was eminent for his knowledge, industry, and talents. There were indeed so many interesting traits in his character, that I trust I shall be excused if I recite a few of the chief circumstances of his history.

He is said to have been a skilful painter upon glass², but he was more generally known as a chemist. Originally he was a land surveyor and draughtsman; but his taste for natural history led him to abandon this employment, and induced him to travel for instruction over the whole of France and Lower Germany. An accidental circumstance threw into his hands a cup of enamelled pottery; and, from that time, his whole attention and for-

¹ The oxides of many other metals are used in different branches of pottery, as will be shown in connexion with the latter part of this subject.

² In the time of Palissy the art of painting upon glass was nearly lost. In this country it was classed with the *ARTES PERDITÆ*; but Mr. Walpole has shown, by a regular series of artists and their performances, that this secret was never entirely lost. Walpole's *Anecdotes of Painting*.

tune were taken up in experiments on enamels¹. Nothing can be more interesting than the narrative which he himself has given of his labours.

He exhibits himself as building and rebuilding his furnaces, always on the eve of success; worn out by labour and misfortune; the derision of the public; the object of the angry remonstrances of his wife; and then as being reduced to such an extremity as to burn his furniture, and even some of the wood-work of his house, to keep his furnaces going. His workman presses him for money, he strips himself, and gives him part of his clothes. But at length, by dint of indefatigable labour, constancy, and genius, he arrived at the desired degree of perfection, which gained him the esteem and consideration of the greatest men of his age.

He was the first who formed a collection of natural history at Paris. He even gave lectures on that science, and received a moderate subscription from each of his auditors, under the obligation of returning it four-fold if any thing he taught should prove false. He was the author of many singular books on subjects of agriculture, fire, earth, salts, &c. that are now very difficult to be found, and it is to him especially that Buffon is indebted for many useful hints.

Palissy was the first who ventured, in the face of the priests, to affirm that fossil shells and calcareous mountains are the remains of real shells; he was also the first who taught the true theory of springs, and was in all respects an eminent and accomplished man.—The very form of his works exhibits a proof of original genius; they consist of dialogues between Theory and Practice, in which Practice is always the instructor, while Theory is represented as a scholar proud of his own understanding, but indocile and ignorant.

The high reputation he acquired, and the obligations under, which his countrymen stood indebted to him, were however not sufficient to defend him from the persecution of the League; for, being a protestant, Matthew de Lawnay, one of the greatest fanatics of his day, caused him to be dragged to the Bastile at the age of ninety years, where he signalized himself by acts of firmness and heroism.

His reply to Henry III. deserves to be commemorated. "My good man," says the king, "if you cannot reconcile yourself to

¹ The modern enamel painting is quite a different art. This was invented by John Petitot of Geneva. An account of his experiments and discoveries may be seen in the *Biographical Dictionary*, article Petitot, and also in Grainger's *Biographical History*, vol. ii. p. 288.

the matter of religion, I shall be compelled to leave you in the hands of my enemies." "Sire," said Palissy, "I was perfectly ready to surrender my life; and if the action could have been accompanied with any regret, certainly it must have vanished, after hearing the great king of France say, 'I am compelled.' This, Sire, is a situation to which neither yourself, nor those who force you to act contrary to your own disposition, can ever reduce me, because I am prepared for death; and because neither Your Majesty nor your whole people have the power to compel a simple potter to bend his knee before the images which he fabricates²." This venerable man died about the year 1590.

Several of the nations of Europe at the dawn of the eighteenth century, could not but regret that the knowledge of the manufacture of porcelain had not been introduced among them. At this time, however, a fortunate circumstance aroused the attention of the French people, and directed it to this important subject.

Francis D'Entrecolles, who had resided many years in China as a Christian missionary, a man of insinuating manners, and of a mild and affable deportment, had the address to procure specimens of the materials used by the natives in their porcelain, and these he sent to France with a summary description of the Chinese processes.

When the specimens arrived in France, the celebrated Reaumur undertook a series of experiments to discover the method of imitating the Chinese productions; and he persevered with amazing industry until he had obtained the main object he had in view.

The difficulties which he had to encounter; the mistakes he made during the investigation; the cause of those mistakes, and the extent of his success, are all well detailed in the French Dictionary of Chemistry, translated by Mr. Keir, and will be found under the article Porcelain. Mr. Reaumur himself in the years 1727 and 1729 also published a full account of his progress in this inquiry, in two memoirs addressed to the Academy of Sciences, and which were printed in their Transactions.

While Reaumur was engaged in these experiments, porcelain was begun to be manufactured in Saxony, and soon afterwards other manufactories of it started up in different parts of Germany. We had also an establishment for making it at Chelsea; and since that period various companies in different parts of England, France, and Italy, have been founded for the same purpose.

The first person who made porcelain for sale in Saxony was the Baron Botgar, and it is probable that his was the first ma-

² Chaptal's *Elements of Chemistry*, vol. ii. p. 90; and the *Biographical Dictionary*, article Palissy.

nufactory of real porcelain in Europe. In order as much as possible to preserve this art as a secret, the works were rendered impenetrable to any but those who were immediately employed in them.

M. De la Condamine, in his journey into Italy, visited a manufactory of porcelain established at Florence by the Marquis de Ginori, governor of Leghorn, where he saw statues and groups half as large as nature, and modelled from some of the finest antiques. He describes the body of the ware as being equal to the best Chinese manufacture, and that it would be extremely beautiful if it had a whiter glazing; but that the Marquis was determined to use only such materials as were found in his own country.

The establishments of the most consequence among the moderns are, one at Dresden; the King of Prussia's own manufactory at Berlin; and the extensive works which belonged to the late King of France at Sevres¹, near Paris. There is also a considerable establishment for the manufacture of porcelain at Montpellier; a descriptive account of which, together with the process for making the peculiar glaze which is employed there, was published some years ago in the *Annales de Chimie*, tom. ii. page 73—85.

Frederick the Second, King of Prussia, had conceived so high an opinion of the importance of the manufactory at Dresden, that when he conquered Saxony he took many of the best workmen away by force, and transported them to his own pottery at Berlin². This manufactory at Berlin since the year 1763 has been carried on for His Majesty's own private account, with success and with good taste. Five hundred men have constant employment in it, and large quantities of the porcelain are annually exported.

Mr. Jonas Hanway, in the account of his travels, has published a particular detail of an immense collection of porcelain which is laid up in the Chinese palace at Dresden. The whole recital would be unsuitable to these Essays; but the following particulars will show how the Elector of Saxony valued himself on account of the perfection to which the manufacture of porcelain had arrived in his dominions³.

“The vaults of this palace,” says he, “consist of fourteen

¹ For an interesting account of the establishment and management of the manufactory at Sevres, see the Memoir of Brongniart, the superintendant of the works. *Phil. Mag.* vol. xiii. p. 342; and vol. xiv. p. 17, &c.

² Wraxall's *Memoirs of the Courts of Berlin, Dresden, &c.* 2 vols. 8vo, London, 1806.

³ The potters of Dresden were always as curious in the management of their ovens as they are in the manufacture of their porcelain. Nothing but white wood is employed for heating the kilns, and this is never used till it is become thoroughly dry.

apartments filled with Chinese and Dresden porcelain. One would imagine there was sufficient to stock a whole country; and yet they say, with an air of importance, that a hundred thousand pieces more are wanted to complete the intention of furnishing this single palace."

"Here are a great number of porcelain figures of wolves, bears, leopards, &c., some of them as big as the life; a prodigious variety of birds, and a curious collection of different flowers. A clock is preparing for the gallery, whose bells are to be also of porcelain: I heard one of them proved, and think they are sufficient to form any music; but the hammers must be of wood."

"Here are forty-eight large China vases, which appear to be of no use, nor any way extraordinary, except for their great size; and yet His Polish Majesty purchased them of the late King of Prussia at the price of a whole regiment of dragoons⁴."

In the course of the narrative, Mr. Hanway mentions one very interesting circumstance, viz. that samples of the *first efforts* to make china in Saxony were laid up by the King of Poland in this palace, together with specimens of all the improvements, in their several gradations, from the first, till the time when the manufactory arrived at its utmost state of perfection⁵; an idea truly philosophical, and which reflects more honour on his memory than the bartering away the liberties of his subjects for pieces of foreign porcelain.

The passion for collecting porcelain has been common in most countries. Dr. Campbell remarks that "to Ormus, at the proper season of the year, resorted the merchants from Persia, Arabia, and Turkey. At these seasons," he says, "the city wore a new face, the outsides of the houses were adorned with cabinets of porcelain and with beautiful paintings; and all the riches of the East blazed in the eyes of the captivated spectator⁶."

The greatest part of the earthenware that is now made in England is manufactured in a particular district of about ten miles extent, well known by the name of the Staffordshire Potteries. Here earthenware has probably been made ever since the time of the Romans⁷; but there did not appear to have been any ambition among the manufacturers to improve the art, or to

⁴ *An Historical Account of the British Trade over the Caspian Sea, with a Journal of Travels*, by Jonas Hanway, 4 vols. 4to, London, 1753.

⁵ The potters in Saxony are so exact in the management of their manufactories, that they employ none but the purest rain-water for soaking the clay; and they prepare the clay only twice a year, at the equinoxes; conceiving that at those seasons the water is less contaminated with foreign ingredients.

⁶ *Political Survey*, vol. i. p. 37.

⁷ In sinking pits very evident remains of Roman potteries have been discovered, and at a considerable depth below the present surface of the land.

produce any works of taste, till the late Mr. Wedgwood engaged in the business. This most excellent man brought modellers from Italy and from other parts of the continent, whom he engaged at high wages; and he also constantly employed a competent chemist in experiments, that nothing might be wanting which could conduce to extend the employment of earthenware throughout Europe, or that could in any way tend to give a permanency to the staple manufactory of the county which had given him birth.

Notwithstanding the energy with which Mr. Wedgwood devoted his inventive talents and chemical knowledge to the improvement of his favourite manufacture, during the course of a long and industrious life, I have no doubt that chemistry might still confer many benefits on the potter's art, if the manufacturers in general would bestow such an education upon their children as would enable them to pay a proper attention to the cultivation of this science.

Impressed with this idea, I have myself frequently inspected several of the largest manufactories of earthenware in this kingdom, as well as many others of inferior note, and have examined their various processes with the utmost care and attention. A residence of several years at Stoke-upon-Trent, in the midst of the Staffordshire potteries, afforded me the best opportunities for this purpose, and enabled me to make those inquiries at my leisure, and to acquire that information, which none but an inhabitant could easily have obtained.

It will not, however, be necessary for me, while giving an account of this manufactory as at present conducted, to go much into detail; because, if this were the object I had in view, it would be necessary to devote a volume or more to the purpose; for I am acquainted with few manufactories in which the operations are more numerous and diversified.

On this account, I shall content myself with giving such an outline of the business as will afford the general reader a correct idea of the nature of the different operations; and at the same time shall propose, for the consideration of the manufacturers themselves, such hints for the improvement of some of the processes, as I conceive to be worth their attention.

Before I proceed to a descriptive detail of the several processes in the manufactory of earthenware, it will be proper to say a few words on the nature of the different materials which are usually employed to form the body of the ware itself.

It is well known that the chief ingredients are clay and flint; the former of which, when pure, is known to chemists by the

name of *alumina*, and the latter by the name of *silica*; and that no kind of earthenware can ever be perfect, unless it be made of a suitable sort of clay¹, and in that proportion only which shall be correspondent to the quantity of flint employed. The experience of ages has confirmed this, and has proved that good pottery, as Vauquelin has remarked, differs from bad, less in the diversity of its elements, than in their proportions. How crude have been the notions of men respecting the chemical nature of bodies! The great Buffon “considered clay to be merely silica attenuated, and, as it were, rotted by the action of water, the air, and the sun.”

Baumé was of opinion that sulphuric acid is a component part of all clays, and that the difference which is observable in different samples of this earth is chiefly owing to variation in the quantity of this acid—but this opinion is also erroneous.

There are four kinds of clay in common use in the Staffordshire potteries, and they are known by the following appellations, viz. *Black* clay, *Cracking* clay, *Brown* clay, and *Blue* clay. The two former are the produce of the south of Devonshire, the others are brought from the Isle of Purbeck in the county of Dorset. With regard to the price of these clays, that of the two first is 14*s.* per ton delivered on board the vessel, or 44*s.* when delivered in the potteries. The price of the two latter is 21*s.* on board, or from 48*s.* to 52*s.* per ton when delivered to the works.

The *black* clay takes its name from the colour which it usually bears, and this is derived from a quantity of bitumen or coaly matter which it contains. This carbonaceous portion is, however, entirely consumed when the clay passes through the potter's oven, for the articles made with it become when properly fired of a good white². It is, indeed, a curious fact, that the blacker this clay is when it is first dug, the more white will the earthenware be which is made with it.

The second kind, called *cracking*, has acquired its name from a property which it has of occasioning the ware to crack during the first process of burning, or while making it into biscuit if by accident a larger quantity than usual of it has been employed. But, notwithstanding this singular property, the manufacturers are fond of it, on account of its extreme whiteness. It is, how-

¹ Macquer's Paper on Clays, in the *Memoirs of the Academy for the year 1758*, is highly deserving of perusal.

² The Roman potters must have learnt that the native clays differ very much in their nature and properties, for they had different names to distinguish them; such as *Argilla* for potter's clay; *Terra pinguis*, black clay; *Leucargillion*, white clay; *Terra sigillaris*, fine clay; and *Tasconium*, the clay for crucibles.

ever, always dangerous to use it unless it be employed with judgement, because it has a peculiar tendency to crack even when mixed with the usual proportion of silica. Every kind of clay, when dried without any admixture, will be liable to this inconvenience; because, if *pure* argillaceous earth be made sufficiently soft to be modelled by the potter's wheel, it will shrink one inch in twelve during the process of drying, and this will inevitably produce the effect in question.

The third kind which I have mentioned, is what is known by the name of *brown clay*. The excellency of this sort is, that it burns white, without danger of its cracking like the last species, although it is liable to another imperfection which is termed *crazing*. Some manufacturers, however, employ this clay largely, while others, on account of this peculiar property, refuse it entirely.

CRAZING is a technical term to denote the cracking of the glaze. It is believed that this generally arises from a defective union of the glaze with the body, owing to the clay, or the mixture of the clay with the other materials, being ill calculated to receive the glaze properly. But may it not be occasioned rather by the glaze itself being not perfectly fusible? I suspect, however, that it more frequently originates from the circumstance of the ware being drawn out of the oven before it has time to cool gradually, and for the glass to become properly annealed. See the article *Annealing*, in the Essay on Glass in this work. If lime be mixed with the materials which form the body of the ware, that will unavoidably occasion the crazing of the glaze.

The fourth kind, called *blue clay*, is considered to be the best, and, indeed, it always costs the highest price. This not only burns white, but it forms a very solid kind of ware, and will bear a larger proportion of flint than any other; and it is well known to potters, that the greater the quantity of silica, the whiter will be the earthenware; though if more of this species of earth should be employed than the clay will admit, it would occasion the goods to crack in the second burning. Both this and the brown clay are now much used for making porcelain.

It requires much practice to be enabled to understand the nature of clays sufficiently to employ them in pottery to the best advantage. Dr. Lewis, in his notes to Neumann's Chemistry, has given the results of many experiments on the mixture of clay with the different earths and earthy compounds for the purposes of making pottery, which may be read with advantage by those who are desirous of investigating this subject.

Silica, or pure flint, as I have stated above, is likewise an im-

portant article in the manufacture of earthenware; forming, in general, a fourth, a fifth, or a sixth part of the whole of the bulk of the prepared mixture or paste, when taken by weight.

There is however one remarkable difference in the properties of silica and alumina, which has a very manifest effect on porcelain. Pure silica is transparent; but the thinnest lamina of alumina is entirely opaque.

Alumina has such an affinity for silica that it will unite with it even in the humid way, and form a kind of mortar, which will harden by time, and be afterwards incapable of decomposition by the action of the atmosphere. This combination is the basis of many of the gems and precious stones.

Much of the flint used in England is brought from the neighbourhood of Larne in the county of Antrim in Ireland; but as this comes out of a bed of limestone, it is not so good for the potter's use as the chalk flint.

It has been suggested by a friend of mine, that an inexhaustible source, for supplying the manufacturers with very excellent flint, would be the sea-shore; and that a person conversant with chemistry might readily examine a few samples of pebbles, and determine which were most suitable for making good pottery. On the coast of Sussex alone, particularly about Brighton, there is enough of *shingle*, as it is called, to serve the whole of England for ages, and at no other cost than the carriage. Such, indeed, is the abundance and inconvenience of this natural production, that it would be worth while for the inhabitants of Brighton to give a small premium to encourage its exportation.

For making the finer kinds of earthenware a considerable quantity of Cornish clay is also used, known commonly by the name of China-clay. This is the decomposed felspar of the granite; and it is prepared in Cornwall by the clay-merchants themselves before it is transmitted to the Staffordshire potteries.

There are huge masses or rather mountains of white granite in Cornwall, and in some parts of the county this is found to be partially decomposed; and it is where this is the case, that the mineral is raised and prepared for the purpose of making earthenware and porcelain, it having been discovered some years ago, by Mr. Cookworthy of Plymouth, that this mineral furnishes us with the true *kaolin*, and also with the *petuntse* of the Chinese.

Granite is composed of quartz, felspar, and mica: and Mr. Gerhard found, in making an experiment on granite, that the felspar melted into a transparent glass; under it the mica lay in the form of a black slag, and the quartz remained unaltered.—Nicholson's *Chem. Dict.*

To render the decomposing granite of Cornwall fit for the

manufacturer, the following method is adopted. The stone is broken up by means of a pickaxe, and then thrown into a stream of running water. This washes off the light argillaceous parts and keeps them in suspension, whilst the quartz and the mica, thus separated, are allowed to subside near the place where the stone is first raised.

At the end of these rivulets are a certain kind of catch-pools, where the water is at last arrested, and time is allowed for the pure clay, with which the water is thus charged, to separate entirely from it. As soon as all the clay has subsided, the water is drawn out of these receptacles. The solid matter is then dug up in square blocks, and laid on what are called *linnees*, which are several connected series of strong shelves, erected so as to allow of a proper circulation of air, in order that the clay may be more effectually dried for sale. It is then packed in casks and sent to the Staffordshire potteries, and elsewhere, under the name of China-clay. Thus prepared, it is extremely white and in the state of an impalpable powder. It may here be observed that none of the native clays are entirely free from foreign ingredients. If pure argillaceous earth be required, it can only be procured from alum, which may be dissolved in water, and then decomposed by an alkali. In this process the pure clay will subside, which should then be thoroughly washed for use.

The price of these Cornish clays is considerably higher than that of any other kind; but for many of the finer purposes of pottery, they are absolutely indispensable. They are very smooth and ductile, and their extreme whiteness is very remarkable. It was analysed by Mr. Wedgwood, and found to consist of 60 parts alumina and 20 of silica.

The Cornish clay is also extremely useful for making crucibles, as it will not fuse by the addition of any of the common fluxes. In using these crucibles, however, they should always be put within others which are of little value; the inner ones will then acquire the heat gradually, otherwise they would be in great danger of breaking.

Besides the clays already mentioned, some of the Cornish granite itself is often used with the clay on account of the binding quality which it possesses, and its knitting as it were the other materials more closely by its fusibility, it being naturally more fusible than the earths usually employed in this manufactory: for it is a curious fact, that neither clay, silica, nor lime, will melt singly; but by mixing these three species in due proportions the greatest degree of fusibility is acquired.

Having thus briefly described the several articles which are most commonly employed in making pottery, it will now be

necessary to explain in what manner these are separately prepared for use.

The flints are managed in this way: they are first burnt in a kiln constructed for the purpose, and somewhat similar in form to a common lime-kiln; and then they are ground between very hard stones by a great power, which is given either by the water-wheel or by a steam-engine. In constructing the apparatus the purity and hardness of the stones are of very material consequence; for should they contain calcareous earth, a portion of this would be abraded during the grinding of the flint, which would prove very detrimental to the pottery of which it formed a part.

To enable the operator to expedite the process, and at the same time to grind the flints finer, a quantity of water is thrown into the mill with them, so that the article, when finished, has much the appearance and the consistence of cream. The health of the workmen is also preserved by this expedient; for, before this method was adopted, the atmosphere of the room often became charged with the finer particles of the flint, which, entering into the lungs, sometimes produced the most disastrous consequences.

The grinding the flint with water was first practised by the celebrated Brindley, well known for his skill in the construction of inland canals. The mills now in use were also invented by him; and are composed of a very hard siliceous stone called chert, which is found in abundance in the neighbourhood of Bakewell in Derbyshire.

I have already hinted, that it is important to attend to the nature of the stone which is employed in these mills, and some years ago I was told of a very severe loss which was sustained by many of the large potters, in consequence of their having been supplied with great quantities of prepared flint which had been ground by stones containing a considerable portion of carbonate of lime, which being mixed with the flint, and eventually with the material itself, occasioned to the body of manufacturers a loss of many thousand pounds.

In order to prepare the clay, it is first mixed with water to the consistence of cream: the design of this is, that it may be the more easily passed through the sieves, and intimately united with the ground flint, which could not be done with uniformity and certainty if these earths were mixed dry.

The mixture of the clay and water in the first instance, is generally effected by means of long wooden instruments, which the men move backwards and forwards with considerable force

throughout the whole mass. It is an operation of great labour, and is distinguished by the term *blunging*.

The ground flint is mixed in a similar way with water, and the stirring is continued until it become one uniform fluid mass. But these earths, the clay and the flint, are always blunged *separately*; because, if otherwise, and the two earths were mixed before being deprived of their impurities, which cannot be done till they are brought into a fluid state, it would be impossible to observe the requisite proportions of each.

The Purification of these earths is effected by a process similar to that which the chemist calls Elutriation. When the earth has been well broken and thoroughly mixed with water, it is put into vats, or other large vessels; and when it has stood long enough for the grosser parts to subside, the fluid containing the finer particles is drawn off by a plug, and reserved for use.

In every preparation of these materials for the formation of earthenware or porcelain, it is of the utmost consequence to attend to the relative quantities of each: therefore, whenever these mixtures of the fluid clay with the flint are to be made, they are always done with some nicety, an attention being paid to the specific gravity of each of the fluids, which is either made heavier, or diluted further with water, as the case may require. The mixture of clay and water after it has passed *once* through the sieve, is generally brought to the specific gravity of 24 ounces the wine pint. A pint measure of the ground flint and water, when in the same state, is usually 32 ounces.

When the clay and the flint are mixed in suitable proportions, the whole mass, in this state of semifluidity, is passed through the sieves to take out any remaining impurities, and also to detain those particles which have not been sufficiently levigated. The mixture is then passed through the finest silk lawn, to ensure the certainty of no unbroken pieces remaining in it, and to reduce the whole to a state of the utmost uniformity and smoothness.

The next object is, to separate the water which has been employed with such profusion, and the readiest way of effecting this is found to be by the direct application of heat. The mass is therefore now poured into very long brick troughs, which are built with flues under them of a sufficient size to afford heat enough to produce an ebullition in the mixture; and this is continued until so much of the water is evaporated as will reduce the mass to the desired consistence.

The evaporation is, indeed, never carried beyond a certain point; because, if this mixture of the earths were allowed to become nearly dry, it would not be kneadable by the usual

methods; neither could it be worked, by the hand or the wheel, into any of those forms which it may be the intention or the interest of the potter to impart to it.

I ought to have mentioned, that the mixture of the clay and the flint with water, is known in the trade by the name of *slip*; that the place in which it is kept is the *slip-house*; and the trough on which it is boiled is called the *slip-kiln*.

When the mixture has been thus brought to a proper consistence, it ought to be kept for a considerable time, that the materials may become more intimately united than they can ever be by mere mechanical force: but in general this is not much attended to, although every manufacturer is fully aware of its importance. Want of room, of time, and often of capital, occasions it to be sometimes used warm from the slip-kiln, and not uncommonly when it has been lying for only a few hours or days. In China it is no unusual thing for the prepared clay to remain from 14 to 20 years before it is thought to be in a fit state for use; and I have heard of some districts where it is customary for a father to prepare as much porcelain-clay as will be sufficient for the use of his son throughout the whole period of his life.

When the dried mass has been removed from the kiln, the next process is that of tempering it, which is effected by first beating it with mallets, and then turning it and beating it again, and again, with small spades, or paddles as the workmen call them, until it is thought to be as well tempered as it can be by these operations.

It should be recollected that this is not pure clay, but a mixture of all the ingredients. Vauquelin says that "Silice constantly forms at least two-thirds of most pottery; alumine from a fifth to one-third; lime from one five-hundredth to one twenty-hundredth part; and iron from the minutest quantity to twelve or fifteen per cent."

The mass, after the operation of beating, undergoes a process called *slapping*. For this purpose it is removed, in the state of large lumps, to a convenient bench or table, where a man having cut it across with a brass wire, unites it again by slapping one of the halves down upon the other with all his force; he then cross-cuts it again and again, and as often unites it by main force, as before.

This cutting the clay in pieces and slapping it together, is a laborious operation; but it must always be continued until the air-bubbles, which the mass at first contained in great abundance, are all driven out of it; because, if the air was not thus carefully expelled from the clay, it would escape when it became rarified in the oven, and this would produce such blisters as would spoil the manufactured goods. On this account the slap-

ping is continued until the mass exhibits, wherever it may be cut, a perfectly smooth and homogeneous surface.

Of late years Mr. Wedgwood and some other considerable potters have, however, employed an apparatus invented by Mr. Thomas Lowe of Nottingham, which effects all these purposes at once. It is moved by a steam-engine, and performs all these operations with a surprising economy of time and labour. It first breaks the burnt flint; it then grinds it in water, and another part of the apparatus performs the hitherto laborious operation of blunging the clay in water and breaking it into a semifluid and uniform mass. When this is done, it is run off and sifted by several sieves of different degrees of fineness, all which are moved by the same power. This earthy fluid then runs down to a lower room, where it goes through other sieves in the same way. In like manner, another part of the apparatus squeezes the dried clay, to save the expensive operation of *slapping*; after which it passes to an iron cylinder full of knives, where it is cut into pieces with great expedition; which saves the expense of cutting it by hand with brass wires, as before mentioned. This receptacle is not properly a cylinder, but a large hollow inverted cone of iron, and the knives are fixed in an upright shaft which revolves within it and passes through its centre. These knives are so contrived that the clay, as it is cut, is forced lower and lower by every revolution, until at last it is pressed by the power of the machinery through a square hole near the bottom of the apparatus, from whence it is removed as it falls, and is carried in blocks to the other parts of the manufactory.

The clay having undergone these varied operations, it is now fit for being formed into any shape, or employed for any purpose, for which it is designed. Accordingly, it is fashioned into various forms by means of a variety of moulds made of plaster of Paris; or put into as great a diversity of shapes by the potter's wheel.

Nothing is found to answer so well for making the potter's moulds as plaster of Paris; because, when rightly prepared, it has the property of absorbing the water so very rapidly from the ware, that it occasions it to slip out of the mould, or to *deliver* itself easily, as the technical phrase is.

To prepare the plaster for making the moulds, it is first ground in a mill exactly similar to that which is generally used for grinding corn by means of a pair of flour stones; it is then baked, or rather boiled¹, to expell the water which is one of its component parts when in a native state.

¹ *Boiled.* This may appear to be an incongruous expression when applied to a dry earthy substance; but the fact is, that when the ground plaster is

This plaster, which is the native sulphate of lime, is boiled in very long brick troughs, having a fire flue running underneath them. The man who superintends the process has a handkerchief tied over his mouth for safety; as the small particles getting upon the lungs, or into the stomach, have been found to be very injurious to the health of the operator.

When this plaster has been thus deprived of water, it is in the state of a soft and impalpable powder; and if its own proportion of water be again mixed with it, it will immediately set into a hard compact mass. It is this property which renders it so peculiarly fit for making the potter's moulds.

The manipulations by which the different articles of earthenware are made, are so various and multiplied, that it would be very difficult, if not impossible, to describe them. They can be known only by those who have had opportunities of visiting a pottery. A short outline of these processes will however be expected from me, and may be acceptable to the generality of my readers.

Much of the common earthenware is formed by means of the potter's wheel, which is a round board attached to a lathe, and capable of being moved thereby, either rapidly or otherwise, as the occasion may require. This round board moves in a horizontal position; and when in use, the clay which is to be fashioned is fixed on the centre of it; and it is put in motion either by a person who constantly attends it when at work, or by means of a treadle which is moved by the foot of the workman himself.

As the clay revolves upon this machine, the workman either models it by his fingers, or forms it, by means of an instrument which he holds in his hand, into any kind of circular shape that he may desire; and when the object is to make a number of vessels exactly similar to each other, the size is generally determined by a gauge fixed without the circumference of the revolving wheel, but projecting over it in such a manner that, whenever the yielding clay is spread out until it touch this gauge, the artist knows that the article which he is making has attained the exact figure which he intends.

The potter's wheel is probably the most ancient of the manufacturing instruments now in use. It was known to the author of that book in the Jewish Scriptures, which claims the highest antiquity of any writings we have, and who must have lived at least 3000 years ago. This simple instrument has however of late years been much improved by adapting a strap to it, which

heated it has so much the appearance of ebullition, that the term which I have employed is made use of by the workmen universally. The finished article is always called *boiled plaster*.

passes over a large taper cylinder of wood, by means of which the artist is enabled to increase or diminish the rapidity of the motion at pleasure. This contrivance is known to mechanics by the name of the *cone pulley*.

In going through a pottery, it will be observed, that all the articles are very thick and coarse when they come from the wheel. This is perhaps unavoidable. They are therefore taken to a lathe, where the extra quantity of clay is removed, in the same manner as the wood-turner forms his work by shaving off successive portions of the wood. These parings of clay are afterwards kneaded as before, and then worked over again for similar purposes.

It is curious to notice the great variety of circular things that may thus be made by means of the potter's wheel; but it must be remembered that this machine is calculated only for cylindrical, conical, or round articles, and not for such as are of an oval or an irregular form. All such are made in plaster moulds, which divide in halves for the convenience of taking out the ware whenever it is found to be sufficiently dry to be removed. The handles of cups and jugs are also made in moulds, and these are afterwards put on the vessels for which they were designed.

The consumption of sulphate of lime, gypsum, or alabaster, (for this substance is known by these various names,) is so considerable for making the moulds for plates and dishes, that in the course of the year many tons of worn out moulds are thrown away as useless. I would suggest, that these might be ground and used as manure, instead of purchasing fresh gypsum for that purpose.

As the plaster moulds absorb water with avidity, the articles which are made in them dry much sooner than would generally be imagined. For instance, the moulds on which the common table-plates are formed, are put into a very temperate stove as the plates are made, and in about two hours the whole will be dry enough to be removed to make room for a fresh parcel. In the usual way of conducting a manufactory, every mould is capable of taking four or five fresh plates in the course of a day of twelve hours. The plate-stove is generally a very small room built with bricks, and shelved with boards from the floor to the ceiling. It is usually heated by an iron pipe which passes through it.

When the plates are removed from this stove, they are taken off the moulds, and pared round the edges with a small knife; and when they have been slightly polished by the hand, they are laid by to become hard enough for the biscuit oven.

From this short account it may be easily conceived that a common-sized pottery must require a great deal of room, especially

as every article, whether made by the wheel, the lathe, or the moulds, must be spread out upon shelves to dry: and this reminds me of an expedient which I lately observed at the works of an ingenious potter in Staffordshire, and which I conceive to be so far an improvement upon the old practice, as to deserve being mentioned, and which I have the leave of the proprietor to make public.

The improvement to which I refer, is that of having a chamber shelved entirely round, not with stones or boards as is usual, but with shelves of prepared plaster made as smooth as polished marble, and of the thickness of an inch and a half each.

Upon these plaster shelves, instead of those of wood and stone as commonly adopted at other works, the goods are placed to dry: and the great advantage which must accrue to the manufacturer from the practice is very obvious; for the plaster not only absorbs the water sooner, but the articles will dry more regularly and uniformly than they possibly can when placed upon substances which cannot abstract the water. Being persuaded of the utility of this expedient, I have no hesitation in recommending it for general imitation. Moreover, why may not the floors of a potter's warehouses be covered with plaster? The expense would be very inconsiderable; and then, whenever these were not in use for storing the finished ware, they might be advantageously employed in hastening the drying of the goods newly made.

In some counties it is usual to form the floors of cheese chambers with plaster, and I have been told that the cheese becomes sooner ripe on these floors than on others; though Mr. Twamley directs that it should not be placed on plaster until time has been allowed for the first moisture to exude and evaporate¹.

An important improvement might be made in the manufacture of earthenware, if it were possible to contrive an expeditious mode of spreading the goods out so as they might always dry gradually. The property which clay has of contracting by heat or by drying is well known, and the excellence of earthenware depends in a great measure on its being very *gradually* dried before it be exposed to the kiln.

When the articles of pottery have been modelled or fashioned to the design of the artist by any of the foregoing methods, and have been partially dried, either by an exposure to the action of the atmosphere, or by placing them for a certain time in stoves or drying rooms constructed for the purpose, they are carried to the potter's oven, where they are placed in deep oval boxes made of fire clay. These are called *seggars*; and being flat at bottom,

¹ Josiah Twamley *On Dairying*, 8vo, Warwick, 1784, p. 100.

one of these vessels forms a cover for another, so that the workmen are enabled without difficulty to place them in piles nearly to the top of the oven, which is a large cylinder of brick surmounted by a dome.

When the oven is properly filled, heat is applied by means of ignited coal, which is thrown into several receptacles built on the outside, but communicating, by means of flues, with the inner part. These are called *mouths*; they stand about four feet in height from the ground, and project about three feet from the sides of the kiln.

In the beginning the heat is kept at a low state; but after a lapse of twelve hours it is gradually increased, and the augmentation of temperature is continued until the kiln and its contents acquire the proper maximum.

An attention to the degree of baking is an object of extreme importance. Vauquelin has remarked that "the heat should be such as to expell the moisture, and agglutinate the parts which enter into the composition of the paste; but incapable of effecting the fusion, which, if too far advanced, will render the ware of so homogeneous a texture as to become brittle."

It has been found that alumina loses 0.46 of its weight even when the fire is not urged beyond the temperature of ignition for silver; whence it appears that it contains nearly half its weight of water, and it does not part with the last portion but with great difficulty.

The operation of burning usually lasts two days and two nights. This, however, varies in the different charges; and the fireman judges when the ware is sufficiently burnt, by examining the trial pieces which are placed in those parts of the oven where they may be taken out with ease, and without causing any diminution of the heat.

These trial pieces are made of the common red clay of the Staffordshire brick-makers. It is found in the Potteries, and has the property of changing its colour at every change of temperature; therefore, by comparing one of these, taken out of each part of the oven, with a trial piece made of the same kind of clay and properly burnt, and which is kept on purpose for a standard, the exact state of the ware under operation may at any time be exactly known.

All the common ware undergoes two firings: that is, when it has been sufficiently dried in the air, it is put into an oven and made into what is called *biscuit*, which is earthenware partially burnt.

Many ladies are in the habit of buying china in the state of biscuit, for the purposes of painting and gilding. When they

have imparted their own designs, these are sometimes returned to the potter, who burnishes the gold and completes the baking. This is mentioned with the view of directing those females who may not be already acquainted with it, to a new object for the exercise of their taste and genius, and also for the better explanation of the nature of biscuit ware.

All the English earthenware and china undergoes this previous firing, because, were it not first made into *biscuit*, it would not bear to be immersed in the mixture of lead and water, called the glaze, without suffering injury thereby: that is, it would not fail to be rendered soft, and liable to be put out of form, by its absorption of the water. Neither would it sustain the process of printing, nor allow of its being painted upon with any good effect.

The composition of the Chinese porcelain is different, and its nature is now pretty accurately known. Mr. John Bradley Blake, who was settled as a resident Supercargo at Canton, and died there at the age of 29, sent, a short time before his death, to Mr. Samuel Moore, the then Secretary to the Society for the Promotion of the Arts, specimens of the earths, clays, sand, stones, and other materials used in making the true Nankin porcelain, all which Mr. Moore put into the hands of the late Mr. Wedgwood, who from these materials produced some pieces of excellent porcelain, and declared that those earths were so complete a set of specimens, that he had no doubt of their being the true materials of the Oriental porcelain. Had Mr. Blake lived, further information would have been procured.

It was ascertained by Mr. Blake, and we have learnt from other sources, that in China the earthenware and porcelain are merely dried in the air before glazing; as their composition so effectually resists water, that it can be immersed in an aqueous glaze, without being first made into biscuit, and consequently that the Chinese are enabled to burn their ware by one single firing.

It is therefore a desideratum with the potters of this country, to find some substance to mix with the clay which shall give it the property of resisting the action of water before it has undergone the first burning. This would be a great acquisition to our English manufacturers, because it would not only be a saving of fuel, but a great economy of time and of the expense of wages, as one operation would be thereby entirely saved.

Dr. Woodward mentions the Soap Rock at the Lizard Point, and the steatites in other places, as very likely to make good porcelain¹. Dr. Campbell also, who seems to understand this

¹ Woodward's *History of Fossils*, vol. i. page 6.

subject, strongly recommends this article to be employed in the manufacture of china¹. Whether steatites will improve the body of the ware, as above mentioned, I do not know, but I know it has been used at some of our porcelain works in considerable quantities.

Should the English potter be able to make the body of his ware equal to that of the East, it would then be necessary, as I apprehend, to discover some other material for the glaze; because, if our ware were burnt, as it is in China, by one operation, the earth would contract more than the glaze, and consequently the latter must either crack, or partially fly off.

I hazard this opinion, because I know that in China the glaze is infinitely better than ours, inasmuch as it consists purely of felspar, and is so extremely hard that it cannot be operated upon by any of our common cutting instruments. Even the wheel of the glass-grinder will not touch it; whereas ours becomes scratched and defaced by common usage and ordinary wear.

If the glaze on porcelain be too thick, this will occasion it to break; it is therefore important to apply a thin glaze, the fusibility of which should be as nearly as possible approaching to that of the body of the ware, in order that the combination may be more intimate and lasting. Chaptal describes a glaze which perhaps our potters may imitate with advantage. "It consists," says he, "in mixing the earth of Murviel in water, and dipping the pottery therein. When dry, they are plunged into a second water, in which levigated green glass is mixed. This covering of vitreous powder fuses with the clay of Murviel, and the result is a very smooth, very white, and very cheap glazing²."

The great durability of the Oriental china is its main excellence. We make porcelain in this country which is equally beautiful; and, if the symmetry of the figures and the merit of the painting be considered, far more elegant, although it possesses a less degree of tenacity and hardness. We have, indeed, lately noticed the introduction of what is called stone-china, which is made very thick and clumsy to imitate some of the best productions of the East: the glaze upon this, however, is as poor and soft as upon other English china.

Is it not natural then to ask, Why do not our potters make use of a better glaze, especially as the county of Cornwall can furnish felspar in abundance and at a reasonable price?

The true answer to this question seems to be this: that our ovens are not capable of fusing a glaze similar to that which is

¹ *Political Survey of Great Britain*, vol. ii. page 19.

² Chaptal's *Elements of Chemistry*, English Transl., vol. ii. page 88.

employed in China. The heat of the potter's oven in that country must be tremendous. The materials could not be vitrified as we see them, with less heat than would fuse Cornish granite.

An ingenious mode of discovering when the glaze on china is not sufficiently hard, has been given by the late Mr. Nicholson. It consists in dropping a small quantity of strong ink upon it, drying this before the fire, and then washing it. If the glaze be too soft, an indelible brown stain will remain upon it.

It must here be remarked, that for those who choose to incur the expense, there is porcelain manufactured in some parts of this kingdom which is more durable than that commonly made in the Staffordshire potteries. Such was formerly the Bow china, and that also made at Chelsea; and I have been credibly informed, the china now manufactured at Worcester is nearly equal to the best Dresden³, or to the true Nankin, in all those properties which give the most value to this production of art.

The common heat of the potter's kiln in England is about 60° of Wedgwood's pyrometer⁴, which is equal to 8877 degrees of Fahrenheit for the cheapest cream-coloured ware, and about 80° of Wedgwood for the Staffordshire porcelain; though I have reason to believe that the manufacturers of the best cream-coloured ware seldom allow the heat of the kiln to exceed 45° of Wedgwood's pyrometer. It must be recollected, however, that we fire twice, and that these heats refer to what are employed in converting the ware into what is called biscuit.

I am not myself acquainted with the respective temperatures at which the other porcelain manufacturers fire their ware; but Dr. Henry has stated that the Worcester china vitrifies at 94, that the Chelsea porcelain is fired at 105, and the Derby at 112 of Wedgwood.

In the Staffordshire potteries the temperature of the gloss-oven is generally about 10° of Wedgwood, or 2377 degrees less of Fahrenheit than the heat of the biscuit oven. The reason of this is, that there may never be any danger of the ware, in this last operation, undergoing a higher degree of heat than it experienced in the first burning; it being absolutely necessary for the operator to be careful of this point, because, as clay will continue to con-

³ Dresden china was formerly in such high estimation in this country, that in the year 1763 a single service of it was sold by auction in London, at Mr. Uthoff's sale, for 115 pounds. *Gentleman's Magaz.* vol. xxxiii. p. 312.

⁴ For an account of the construction of Wedgwood's pyrometer the reader is referred to the lxxiid and several of the subsequent volumes of the *Philosophical Transactions*, or to Murray's *System of Chemistry*, vol. i. p. 150. The pieces of baked earth which he employed for the pyrometers were analysed by Vauquelin, who states them to have consisted of silica 64, alumina 25, charcoal 6, oxide of iron 0.2, water 6.2. Nicholson's *4to Journal*, vol. iii. p. 265.

tract by every addition of heat, it must follow, that should it ever be pushed beyond that degree which it sustained in the state of biscuit, the body of the ware would experience a greater contraction, and consequently every piece within the oven would either become crooked, or the glaze would be injured. The firing of the gloss-oven generally requires from 12 to 14 hours.

The glazing for the common cream-coloured earthenware consists usually of certain portions of litharge of lead and ground flints, mixed with as much water as will form them to the consistence of thin cream, which is found to be a state the most suitable for the immersion of the ware. One hundred pounds of litharge and 40 pounds of ground flints are the common proportions; but it is usual to take 80 pounds of Cornish granite to 100 pounds of litharge, whenever that is used instead of flints. Flint is the article which is employed in making glaze for the porcelain as well as for the coarse earthenware, it being nearly all silica. Klaproth found common flint to consist of ignited silica 98 parts, lime 0.50, alumina 0.25, ignited oxide of iron 0.25 parts, volatile in the fire, 1.—*Analyt. Essays*, vol. i. page 42.

For the finer kinds of earthenware and for porcelain, it is made with white lead, ground flint glass, ground silica, and common salt. Some manufacturers, however, add other materials; most of those who superintend this department imagining that they possess a valuable secret, and that in consequence of it their glaze is much better or cheaper than that of others.

In all manufactories it is found necessary to vary the composition of the glaze, according to the nature of the materials which form the body of the ware; and the former cannot be perfect unless it be capable of contracting and expanding by heat and cold, in the same proportion as the ware itself will contract or expand by change of temperature. The writer of the article Porcelain in the French Chemical Dictionary very properly remarks that "a glass which makes a fine glazing for one porcelain, will make a very bad glazing for another sort of porcelain, will crack in many places, and have no lustre. The glazing must be appropriated to the density of the ware and the ingredients of its composition."

As the number of potters has increased very much within the last 50 years, the competition has become so great that every manufacturer is under the necessity of consulting economy, and of sometimes sacrificing the utility and goodness of the ware, for the sake either of appearances or of adopting the cheapest modes of manufacture that can be devised.

To one of these causes, may be attributed the introduction of bones into the manufacture of porcelain. Of this article there is now so large a consumption in the Staffordshire potteries, that

some of the great manufacturers have extensive rooms which are used solely for the reception of bones. Animal bones are composed of lime and phosphoric acid, in different proportions according to the age and species of the respective animals to which they belonged. These are either bought of the indigent bone-collectors in the country, and then burnt and ground by the potter, or they are purchased ready burnt and ground for use, directly from those who distill volatile alkali or spirit of hartshorn. It is, however, generally known to the china manufacturers, that this article is injurious to the texture of the ware: its use, therefore, cannot be justified on any account whatever.

I allow that ground bones have the effect of rendering the goods very white, and also that they produce a transparent appearance; but I doubt whether this be a real transparency, or only a deception. Thus far, however, one may venture to assert, that the modern English porcelain, which has the usual proportion of bones in its composition, is of much less specific gravity than it ought to be, and is very apt to crack with hot water. As the base of animal bones is phosphate of lime, it might be worth while for the potter who is determined to use bones, to try whether the *native* phosphate of lime can be useful in making porcelain, and if phosphate of alumina may also be employed in this manufacture.

In returning to the subject of glazing, it will be proper to state that the common earthenware would be too porous, and many kinds of fluids would pass through it, were it not defended by an artificial covering or permanent glaze. It became necessary therefore to contrive a composition which should vitrify and flow in the fire, so as to cover these materials of earth with an entire coating of perfect glass.

Such a glaze having been found in a mixture of oxide of lead and silica, as mentioned above, a certain proportion of each of these, ground to an impalpable powder, is thrown into a tub of water, and stirred therein till the mixed powder becomes suspended and uniformly dispersed throughout the fluid.

The glaze having been thus prepared, it is applied to the ware in the following manner. A workman to whom this duty belongs, receives the goods from a boy, who delivers them to him one at a time; and as he receives each single piece, he dips it in the liquid, lets it drain for a moment, and then, placing it on a board standing beside him, he is ready to receive another piece, which he immerses in like manner.

It is in this way that the glaze is applied to all the various articles which are made of the common earthenware; and as it is only partially baked or in the state of biscuit, when it is im-

mersed in the glaze, a sufficient quantity attaches itself to the surface, which, when it has been fused, will form over it a complete covering of glass. This mixture has great fusibility, though silica alone does not melt in the focus of the most powerful burning mirror. Mr. Hare, however, fused it completely by submitting it to the flame of a stream of mixed oxygen and hydrogen gases, and found that it formed when cold a kind of enamel.

There are, however, strong objections to this mode of glazing pottery. The men who work in it for a considerable time are apt to become paralytic, probably from the lead; and where acids, which have the power of dissolving the lead, are employed in preparing condiments for our food, such a glaze must be extremely unwholesome.

Aware of the pernicious effects of lead, when taken into the stomach, M. Fourmy, an ingenious manufacturer at Paris, has prepared water-coolers, in which he has employed lava for the glaze, instead of the deleterious metallic covering which is more commonly used for that purpose. Pumice-stone has also, as I understand, been used for covering earthenware, and with very good effect.

Some of the French potters, at the suggestion of Chaptal, have substituted common flint glass for lead in their glazing, and have found it not only safer, but more economical. They grind broken flint glass to a fine powder; and when this is mixed with a due portion of clay and water, the goods are dipped into it, as our potters dip their ware.

The potters of Bristol and Lambeth glaze their stone ware with common salt. When the oven has acquired a certain temperature, the salt is cast in, and the vapours arising from it attach themselves to the goods, and completely cover them. The alkali of the salt probably combines with the silica of the ware, and forms a true glass upon their surfaces.

The English potters are however fond of using a glaze made with lead and silica, because, whatever the articles may be which are employed for this purpose, it is necessary to give them a heat sufficient to vitrify the materials and convert them into a perfect glass; and when the best articles are made use of in forming a glaze, the heat which is employed must be very considerable; whereas lead alone will readily fuse and form a glaze that may be finished at a very low heat indeed. This, however, if used alone, would make a glaze too soft, and so extremely fusible that it would be apt to run very much towards the lower parts of the ware, and leave the upper ones imperfectly covered.

Half a century ago our potters were so careless in their manner of applying the salt glaze to the stone wares of Staffordshire, that large importations were made from France and Holland,

where the manufacture was better conducted; and had it not been for Mr. Wedgwood's timely invention of the Queen's-ware, it is probable that the best part of the trade would long ago have been lost to this country.

A variety is sometimes given to the glaze by mixing certain oxides of the metals, especially that of copper, or otherwise the filings of copper; but this coloured glaze is generally applied only partially, and merely for goods of inferior quality. The edges of common plates are sometimes coloured by this method¹.

It is about sixty years since the plain cream-coloured ware of Mr. Wedgwood was introduced. At that time this unadorned and simple article was thought sufficient for every purpose where porcelain was not employed; and the neatness and cleanliness of its appearance gave it such a decided preference that her late Majesty allowed the worthy inventor to call it *Queen's-ware*; but, when a demand arose for more expensive services of pottery, recourse was had to the pencil. From that period a great number of artists have been constantly employed in painting earthenware as well as porcelain, and often great taste is displayed in these productions.

It must not however be imagined that painting on earthenware was a new invention. The paintings of the ancients of this kind are rare and valuable. The Marquis Marcello Venuti, in his description of the curiosities found in the ancient city of Heraclea, speaks of one upon *slate*, representing a muse crowned with laurel, with a musical instrument hanging on her shoulders, which was found in one of the subterraneous cavities, and is described as being then in the possession of Signor Nicolo Vagnucci of Cortona, one of the principal supporters of the Academy of Tuscany.

Nevertheless, it must not be concealed that Chaptal has shown, that the Romans of the first century were not acquainted with any of the metallic fluxes with which the moderns fix and vitrify the coverings of their pottery. For the particulars consult his very instructive account of certain colours which were found in the shop of a colour-merchant in one of the streets of the ancient Pompeia, especially as he has there told us what was the composition of the glaze which the potters of that day did actually employ².

To return to the consideration of the paintings on English

¹ The beautiful black glaze, which is seen on a peculiar sort of ware made at Nottingham, is composed of 21 parts by weight of white lead, 5 of flints, and 3 of the oxide of manganese. Watson's *Chemical Essays*, vol. ii. page 271.

² *Annales de Chimie*, tome lxx. p. 22.

earthenware, it must be observed that the variety of effect is produced by means of the different metallic oxides, each of which affords a different colour, and these colours are again multiplied by such mixtures of two or more of the oxidized metals, as experience has shown to be useful.

In employing these various colours, the ground oxide is first mixed with a prepared flux, which is also reduced to an impalpable powder, and then this mixture is well incorporated with gum water, the acid of tar, oil of turpentine, or some other essential oil, as may be most suitable, in point of expense or otherwise, for the goods on which it is to be employed. The fluids are used merely to lay on the colour; for it is necessary that, whatever oil be employed, it should have the property of evaporating entirely.

The preparations which are commonly used, are the metallic oxides and their combinations with acids. Thus cobalt yields a blue; antimony and silver give yellows and oranges; platinum a silver colour; gold violet and purple; copper the greens; while the reds, the browns, and the blacks, are derived from iron.

The oxide of cobalt employed in the pottery is usually prepared from zaffre, which is an expensive article imported from Saxony, though a few years ago very fine oxide of cobalt was procured from Cornwall; for preparing antimonial yellows, the crude antimony is first calcined with four times its weight of nitre, and is then mixed with a certain proportion of vitrified lead. The precipitate of Cassius is the article which is generally used for the production of violets and purples, though sometimes the oxide of gold precipitated by copper is employed. For greens, the copper has usually been taken in the state of a precipitate; but some potters have found an article of more value in the pure oxide of copper, which they procure by placing sheets of copper in the ovens in which the ware is glazed: and it has lately been discovered that a small portion of copper mixed with the iron very much increases the intensity of the blacks on earthenware. Besides, iron itself is capable of giving a great variety of colours, according to the way in which it is managed. For instance, the black oxide of this metal produced by the action of heated air only, will be a very different article when used as a pigment from an oxide of iron prepared by other means.

It is here necessary to remark, that in painting on the biscuit no oil is used; the metallic oxides are mixed with water only; and it is owing to this circumstance that such ware may be glazed at once without being put into an oven, as is the case with those goods which are known by the appellation of *blue-printed*.

For certain purposes, however, the painting is performed upon

the glaze, as some colours would be injured, and others destroyed, by the heat of the gloss-oven. Thus, where iron is employed to produce blacks or browns, the painting is always done *upon* the glaze; the ware is then finished in an enamel-oven, at about 6° of Wedgwood's pyrometer.

Some metallic oxides are used for another purpose besides that of painting, viz. for covering the ware entirely on the exterior, as is the case when the sulphuret of antimony is employed for producing a common kind of yellow ware; and also for those articles known by the names of GOLD and SILVER LUSTRE. The first of these lustres is effected by means of gold, the latter by the oxide of platinum. For gilding porcelain the metal is used in its metallic state. To procure it in a pulverized form, it is dissolved in aqua regia, and then the acid is driven off by heat, and the gold remains; this is then mixed with borax and gum-water, which form together a proper vehicle for fixing it upon the goods. After this it is baked, and finished by burnishing.

For preparing the lustre-ware, as it is called, the oxide, of whatever kind it may be, is mixed with some one of the essential oils, and in that state it is brushed upon the surface of the articles. It should have been observed, that when the manufacturer intends to make lustre-ware, the articles are glazed *before* the gold or the platinum is applied. For *gold-lustre*, the ware is made of a red clay, which, when burnt and glazed, shows so much of its colour through the covering of gold, as is sufficient to give the goods that peculiar brown tint which is always observable on this singular kind of pottery.

When the metallic oxide has been properly applied to the surface of the goods, they are carried to an enamelling-oven, where the heat dissipates the oxygen, and restores these precious metals to their metallic state,—I cannot say quite to their primitive metallic brilliancy, because this is often much injured by the fluid menstruum employed in the operation. The great difference which there is in the appearance of this ware, especially in that which is covered with platinum, can only be thus accounted for. Some of it looks like silver, while the articles from other manufactories are more like iron or steel.

I once imagined that this variation might arise from a different mode of preparing the oxide of platinum. I therefore prepared two samples of this oxide, the one precipitated by caustic ammonia, and the other by muriate of ammonia; but when I had them tried by an experienced potter, both produced precisely the same colour.

I wish some manufacturer would attempt to produce this ware by mixing the oxide of platinum with pure water only; for in

that case I am persuaded the ware when finished would be as white as the platinum itself.

The potters of England have derived great advantage from the introduction of the printing-press. The use of this valuable machine, which is comparatively of late date, has enabled these manufacturers to produce a greater variety of patterns, and of neater execution, than could possibly be acquired at a small expense by the pencil.

As this is a curious branch of the business, it will be proper to describe it a little more particularly. It consists in first printing the intended pattern with some metallic colour, chiefly the oxide of cobalt, on what is called *silver* paper, and then in transferring the colour from the paper to the surface of the porcelain. This style of colouring earthenware is a very successful imitation of the old blue porcelain of China, and of late years has been the means of extending the consumption of British pottery throughout Europe more than any other improvement in the manufactory; for the potters of China are totally unacquainted with the printing-press, and consequently all their designs are produced by the pencil alone.

This mode of imparting designs to the surface of earthenware or porcelain, and which is known in the trade by the appellation of BLUE PRINTING, is managed somewhat in the following manner:

One man constantly attends the press, which is very similar to our common copper-plate printing-press; and as soon as he has applied the colour—which is laid on the copper in the same manner as the copper-plate printers apply the ink—he lays it upon a hot iron, to thin the oil with which the colour is always mixed for this purpose. The oil which is used is a peculiar preparation of boiled linseed oil. When the colour upon the copper-plate is thus reduced to a proper consistence, a sheet of silver paper is laid over it, and the workman passes it, with the paper, through the press.

For blue printing, the oxide of cobalt is the only mineral which is employed. This is largely prepared in the Staffordshire potteries, and sells at from 40s. to 60s. the pound, according to its intensity and goodness. Indeed, such improvements have been made in the manufacture of this colour, that the Chinese potters are now supplied from England with all the cobalt they consume.

When the paper comes from the printing-press, it is, of course, found to be stamped with the intended pattern. It is then delivered, while wet with the colour, to a girl, who cuts off the superfluous paper with a pair of scissors, and passes it to another

girl, who immediately applies it to a piece of biscuit ware, and then delivers it to a third, who fixes it more firmly by rubbing it very hard with a piece of flannel tightly rolled up in the form of a short cylinder.

The design of this hard rubbing is to force the colour into the pores of the ware. When the papers which have been thus applied have lain on for about an hour, the colour is generally found to be sufficiently fixed to admit of their being detached. This is effected by putting the articles into a tub of water, where the paper soon becomes soft and pulpy enough to allow of its being peeled off by gentle friction, leaving the full impression of the pattern upon the biscuit.

The papers having been removed, the ware is suffered to stand a sufficient time to become dry, and then it is put into an oven at a low heat, for the purpose of dissipating the oil, and preparing it for receiving the glaze.

It must be obvious that it is necessary to employ a glaze which is transparent, in order to give full effect to the brilliancy of the cobalt colour. A little of this blue oxide is also generally mixed with the glaze, for the same purpose as laundresses employ smalt with their starch, viz. to increase the whiteness, by subduing any yellow tint that might otherwise impair its lustre.

Here I cannot avoid observing, that it would be an important acquisition if some suitable article, instead of oil, could be discovered for mixing with the colours which are employed in printing on earthenware, and which could be of such a nature as not to require to be burnt off previously to the application of the glaze. It appears to me to be worth while to institute a series of experiments for this particular object; because, if it could be attained, what immense quantities of printed goods, besides those which are ornamented by the pencil, might be completely finished with two firings, instead of three, which, on the present plan, such goods always require! Were it on no other account than the expense of this vehicle, it is desirable to find a substitute. Some of the first enamel-painters think it necessary to use even the best rectified oil of amber, and this, of late years, has been very costly.

It was my intention to have offered some remarks on the manufacture of crucibles, retorts, and other chemical vessels, which are required to sustain a great heat; but having already extended this Essay much beyond its proposed limits, I must content myself with merely referring to those authors who have already treated on this subject. The most important of these is Pott, who wrote a work expressly upon it¹, as I have already mentioned.

¹ *Lithogéognosie Pyrotechnique, ou Examen Chymique des Pierres et des Terres*. 12mo, 2 vols. Paris, 1753.

I shall detain the reader, however, just to notice that the chief difficulty which the manufacturer finds in preparing such utensils as crucibles, &c. is, that if the portion of silica were employed which is necessary to give sufficient compactness, the ware would, from this very circumstance, be liable to become useless; because many of our chemical articles have the property of dissolving silica. An expedient has therefore been adopted of mixing a large portion of old pottery with the fresh clay, which gives it the desired weight, and yet is not liable to be dissolved by the alkalies, like pure flint or sand.

I am informed by a Sheffield manufacturer, that their cast-steel makers mix ground coke with the best Stourbridge clay, and that their crucibles for melting steel are made with this mixture. Pure earthenware is not fit for crucibles, or for any vessels that must expand or contract by change of temperature. This has been long known; Dryden notices it in one of his poems.

It is said that in France the very best crucibles which they have, are made with fine clay mixed up with old ground butter pots; and that these are composed of a peculiar kind of stoneware, which is manufactured in Normandy¹.

Where crucibles are required for melting metals, those made with plumbago are decidedly the best; but these are unsuitable for other purposes of the laboratory, especially when salts and alkaline fluxes are employed in any process.

More than eighty years ago the celebrated Reaumur, in making some trials on glass, discovered, that if a vessel made of the common green bottle-glass be submitted to the heat of a potter's oven, imbedded in a mixture of sand and ground *sulphate of lime*, the glass of which it is composed will be changed in its appearance, and acquire some of the properties of the best Oriental china; become so hard as to strike fire with steel; be semi-transparent like porcelain, and will endure sudden changes of temperature without breaking. An account of these results was given in the *Memoirs of the Royal Academy of Sciences* for the year 1739.

The subject, however, appears to me to be highly deserving of still further investigation, especially as useful vessels of a difficult form may be made more easily of glass than of earthenware. If, therefore, a cheap and certain method of performing this species of cementation could be adopted, the operative chemist would have it in his power to procure a greater variety of chemical vessels, and those not only more durable but of more convenient forms, than he can possibly obtain by any other means. I wish some potter would commence a manufactory of this kind. Such ware would be highly useful for many domestic purposes, to which none

¹ See the article Pottery in the second vol. of *The French Chemical Dictionary*.

of the common pottery can be applied either with convenience or safety.

In returning to the subject of earthenware, it is proper I should state my opinion, that chemical vessels are often injured by the oxide of iron originally pertaining to the clay itself, as it acts like a flux, rendering this earth too fusible to admit of a proper union with the siliceous material of the ground pottery, which is employed in the manufacture of such articles. A question arises here, whether *oxide* of iron alone is prejudicial in this way, although its sulphuret, the pyrites, may. It may, perhaps, be worth while to decide this by experiment. Macquer says, that if a bit of pyrites be left in clay which is to be exposed to a baking fire, it will form a cavity in the ware, and that this may be known by the circumstance of the cavity being stained black.

There is an old pamphlet of nine pages in the London Institution, without title-page or date, on making porcelain, in which the writer speaks of a practice the Chinese have of purifying the earth they employ for the glaze, by means of aqua-fortis. On reading this, it occurred to me, that it might perhaps be worth trying, whether this expedient could be adopted with advantage in purifying such of our clays as are designed for the finest purposes.

For those articles in which the chemical nature of the body of the ware is of importance, it would perhaps be advisable always to wash the clay thoroughly; for, if pyrites be contained in it, the greater part of this would subside, on account of its superior specific gravity, while the argillaceous earth remained suspended by the water. For chemical jars, still-heads, &c., a *small* portion of iron would probably not be injurious. Vauquelin analysed the clay of which Hessian crucibles are made, and found it to consist of 8 parts oxide of iron, combined with 69 of silica, 22 alumina, and 1 carbon.

Clay which contains lime is equally improper for the manufacture of chemical vessels. If a clay be suspected to contain lime, or rather carbonate of lime, it may readily be discovered by an acid, which, if this earth be present, will occasion an effervescence. When lime does not exceed five or six per cent., it appears to do no harm to the quality of the pottery; but when more abundant, it communicates too great a degree of fusibility: in like manner there are cases in which an admixture of the oxide of iron is useful and even necessary.

In the manufacture of what is called Delfware it has been customary to mix a portion of ferruginous clay with the other ingredients, because of its possessing a binding quality from which other species are exempt. The following are the usual proportions: Two parts of red clay, three of blue clay, and five of marle².

² See Macquer's *Chemical Dictionary*, article Delfware.

Most of the red clay is indebted to iron for the colour which it assumes ; but when iron enters in any considerable quantity into the composition of the finer kinds of earthenware, it imparts either a red or a brown tinge to it; and besides this, it adds more fusibility to it than even lime.

Recollecting the circumstance just mentioned respecting delfware, it occurred to me, in reading one of the volumes of the *Archæologia*, that a certain iron-ore found in Scotland would probably be useful, when mixed in a small proportion, for some articles of pottery. I will give an abstract of the passage which caught my attention ; and if any ingenious manufacturer should be able to avail himself of this hint, and convert it to profit, I shall be rejoiced, and shall at any time be glad to be informed of the result, and the respective particulars which attended it.

In the Highlands of Scotland some very singular ancient walls are to be seen, which consist of “ stones piled rudely upon one another, and firmly cemented together by a matter which has been vitrified by means of fire, and which forms a kind of artificial rock that resists the vicissitude of the weather, better than any artificial cement that has ever yet been discovered.”

Mr. James Anderson, the person who has written upon these curious remains of antiquity, has found that through all the northern parts of Scotland, a peculiar kind of iron ore of a very vitrescible nature is in great abundance. Hence he supposes that “ when the walls were reared and made as firm as could be by dry stones piled one upon another, the interstices between them were filled with this vitrescible iron ore, and the whole supported by a backing of loose stones piled behind it. When this wall was thus far completed, nothing more was necessary to give it the entire finishing, but to kindle a fire all round it, sufficiently intense to melt the vitrescible ore, and thus to cement the whole into one coherent mass.”

Dr. Lewis has related a remarkable instance of the affinity of iron for silica. Having immersed some pieces of green glass in the red oxide of iron which remains after the acid has been expelled from green copperas, and baked it for several hours in the upper chamber of a wind furnace, the glass and oxide of iron were found to have run together into a black mass, of sufficient hardness to strike fire freely with steel. “ It is remarkable,” says he, “ that a metallic substance so refractory in the fire, should be so greatly disposed to melt with green glass¹.”

Nothing can be of more importance to a potter than a thorough knowledge of the properties of the different kinds of clays. Dr. Campbell, in his Political Survey of Great Britain, states that we

¹ *Commercium Philosophico-Technicum*, p. 245.

have not less than twenty-two distinct species²; and Macquer, who examined more than eight hundred specimens, says that in all that number he did not find one that was entirely free from metallic matter³.

There is only one method, however, by which clays can be examined with any accuracy, and that is by the aid of chemistry. Such of my readers who are potters but not chemists, will therefore allow me to advise them to lose no time in acquiring the knowledge of analysing earths and minerals. Ample directions for the attainment of this art will be found in Kirwan's *Elements of Mineralogy*, or in Klaproth's *Analytical Essays*; and I conceive it impossible that any manufacturer will ever regret the time which it may be necessary for him to devote to the acquisition of that elementary knowledge which would enable him to consult these distinguished writers with pleasure and advantage.

One or two instances of the mistakes which may occur in the examination of mineral substances, when they are not submitted to chemical analysis, will be sufficient to show the importance of this inquiry, and will, I hope, induce the junior practitioners at least, to adopt this advice, and enter upon that course of study which will be most likely to afford profit as well as entertainment.

The precious stones were formerly classed with siliceous fossils; and until Bergman and Klaproth analysed several of them, they were generally supposed to be entirely composed of silica combined with a portion of colouring matter, to which they were solely indebted for their distinctive characters and appearances. An accurate analysis of several of these gems, particularly of the Sapphire, the Topaz, the Hyacinth, and the Ruby, has, however, proved that either alumina, or zircon, and not silica, is in these instances the predominant ingredient. The Sapphire, according to Klaproth, consists of clay 98.50, oxide of iron 1, lime 0.50. The Topaz consists of clay 46, silica 39, lime 8, iron 6. The Hyacinth of zircon 70, silica 25, oxide of iron 0.50, loss 4.50⁴. The Ruby is composed of clay 40, silica 39, lime 9, and iron 10⁵.

The well-known article called Fuller's Earth, from its saponaceous texture had been supposed to consist almost entirely of clay or alumina; but, on an accurate analysis, it has been ascertained that the earth which enters into its composition in the largest proportion is silica. According to the analysis of Bergman, Fuller's Earth consists of silica 51.8, alumina 25, lime 3.3, magnesia 0.7, iron 0.7, water 15.5. Hence it may be accounted for,

² Campbell's *Political Survey of Great Britain*, vol. ii. p. 16. Morton's *Natural History of Northamptonshire*, p. 71.

³ Macquer's *Memoir upon Clays*, presented to the French Academy in 1762, and abridged in the *French Chemical Dictionary*, under the article Clay.

⁴ Klaproth's *Analytical Essays*, vol. i. p. 198.

⁵ Bergman's *Essays*, vol. ii. p. 101.

why it falls into a powder when put into water, and is incapable of forming a ductile paste. On the contrary, Emery, which has very much the appearance of sand or ground silica, is for the most part argillaceous earth or alumina, and the siliceous earth is in a very inconsiderable quantity.

The last instance which I shall adduce is one that is intimately connected with our subject, and which shows decisively how necessary it is for a potter to be capable of undertaking a chemical analysis.

The porcelain earth of Baudifféro was pronounced by Macquer and Baumé to be a CLAY superior in quality to that which was then employed in the manufactory belonging to the French King at Sevres; and on their authority this was generally believed, till Mr. Giobert discovered that not a particle of clay could be found in it. For, when this chemist attempted to convert it into alum, he found, to his great surprise, nothing but very pure crystals of Epsom salt, or sulphate of magnesia. After this, Giobert analysed this mineral with great care, and found it to consist of magnesia 68, carbonic acid 12, silica 15·6, sulphat of lime 1·6, and water 3¹.

Since that period magnesian earth has been much employed in the composition of porcelain, it having been ascertained that a small portion of it prevents that great degree of contraction which always takes place in the fire, when clay and silica alone are made use of. The Cornish steatites or soap rock being a mineral containing magnesia, some of the English potters now employ it for this purpose.

There is a clay found in the territory of Sienna, in the province of Tuscany, called *fossil meal*, and by Kirwan Argillomurite, which is capable of making hard compact bricks that will float in water, either baked or unbaked. M. Fabroni, who examined some of these bricks in consequence of their having been mentioned by Pliny², says that they may be of great use in the construction of reverberatory furnaces; for they are such bad conductors of heat, that although one of such bricks should be made completely red-hot from one end to its middle, any person may take it up in his hand by the other end with impunity³. May it not then be worth while to inquire, whether a clay possessed of similar properties cannot be found in Great Britain?

Moreover, considering the improvements which have been made in the manufacture of pottery, might it not be easy to make bricks to imitate stone, and yet be as durable as the bricks now in use?

By means of the metallic oxides, would it not be possible at a

¹ Nicholson's *Journal*, vol. xii. p. 277, from the *Journal de Physique*, vol. lx.

² See Pliny's *Natural History*, lib. xxxv. cap. 14.

³ See *Philosophical Magazine*, vol. ii. p. 180.

cheap rate to stain bricks of any colour, and might not such bricks be made to imitate marble?

A method of employing sulphate of barytes in pottery is indeed alluded to by Sage, in the *Journal de Physique*. "The Chinese," says he, "know the remarkable property which gum adracanth has of giving a coherence to minute stony substances, which are then unalterable by fire; and that if this gum be mixed with pounded sulphate of barytes, it may be formed into masses which neither alter their shape nor solidity from exposure to an intense fire." I have not heard that any English potter has yet availed himself of this suggestion.

In concluding this Essay, I trust I shall stand excused, if I endeavour to confirm an opinion already given, that a potter should never employ a new porcelain-clay without previous analysis; for there are few of these clays that can be employed with the certainty of a good result, unless some fusible material be used with them; and the quantity of this can only be known by a chemical examination of the clay in question. The necessity of analysis will appear from the comparison of the chemical nature of three of these native productions. The porcelain earth of Limoges, and which is often used without any admixture, is, according to Hassenfratz, composed of 62 parts silica, 19 alumina, 12 magnesia, and 7 sulphate of barytes; whereas the porcelain-clay of Cornwall is a compound of 20 per cent. of silica and 60 per cent. of alumina; while that found in the department of the Loire in France, of a beautifully white colour, consists entirely of carbonate of magnesia and silica.

The business of a potter affords so large a field for the exercise of taste and genius, and the art itself is so intimately connected with chemical knowledge and experience, that it would be superfluous to urge, by further arguments, the absolute necessity of cultivating the science of chemistry, in order to arrive at perfection in any branch of the manufacture.

ESSAY XI.

ON THE MANUFACTURE OF GLASS.

AMONG the various productions of art, there is, perhaps, no one so truly surprising, when we consider the materials from which it is formed, as that of glass. It is the only instance that I recollect of a substance perfectly transparent being produced by the union of two dissimilar and entirely opaque bodies. Many of the ancients who wrote on Glass seem however to have known nothing of its real nature. Agricola, lib. xii. "*de Metallis*," calls it a concrete juice; Vincent Belluascensis, lib. xi. calls it a stone; and Fallopius classes it with the middle minerals.

The word Glass is generally considered to be derived from the Latin word *glacies*, in consequence of its resemblance to ice.

The date of this elegant and useful invention is involved in great obscurity. According to Pliny, the first vessels of glass were made in the city of Sidon¹; but Loysel asserts that the glass works of the Phœnicians were in high renown more than three thousand years ago, and that they had merely depôts for the sale of their glass at Sidon and at Tyre². The Egyptians also lay claim to having first made it, and say that they were instructed in the art by the great Hermes³.

Flavius Vopiscus, who wrote the lives of Tacitus and others, in the reign of Dioclesian, observes, when speaking of Alexandria, that "it was very rich, abounding in corn; and that no one in the city was idle, for that one part of the poorer inhabitants were employed in the manufacture of paper, and the other in making glass." A late traveller who explored the interior of Egypt, has also assured us that the ancient inhabitants of that country made glass⁴.

Pliny attributes the invention of glass entirely to chance, and relates, that it was first made in Syria by some mariners who were driven on shore on the banks of the river Belus; and who, having occasion to make large fires on the sands, burnt the kali which abounded on that shore; and that the alkali of the plant uniting

¹ Pliny, lib. xxxvi. cap. 26.

² *Essai sur l'Art de la Verrerie* par le C. Loysel, 8vo., Paris, an viii. *Discours Préliminaire*, p. 1.

³ Blancourt's *Art of Glass*, p. 9.

⁴ Belzoni's *Researches in Egypt*, &c. quarto, p. 173.

Crown Glass

S. Parker delin.

J. W. Davis sculp.

The above Figures represent the different forms which the metal assumes in succession during the manufacture of Crown glass as described in Essay XI. page 295.



with a portion of the sand on which the fire stood, produced the first stream of melted glass that had ever been observed⁵.

However this may be, there can be no doubt of glass having been in use during the time of Pliny, as it is often mentioned not only by him, but by many contemporary authors. The city of Herculaneum, which was destroyed about this period by an eruption of Vesuvius, contained glass. Besides utensils of glass, a large sized plate of the same compound was taken from one of the excavations. Josephus relates, that not far from Mount Carmel there is a round valley full of a clear sand fit for making glass; and that when the place has been emptied for this purpose, the wind from the mountains fills it again immediately⁶. But this historian could have known nothing of the nature of the manufacture of glass; for he asserts, that any metal when thrown upon this sand will be instantly converted into glass, and that, if glass be cast upon it, the glass itself will likewise be changed into sand⁷.

Tacitus mentions the river Belus, but he speaks more rationally of the glass which was made in that neighbourhood than Josephus. He says, that this river flows into the sea of Judea, at the mouth whereof, the sand that is taken up, in consequence of the great quantity of nitre contained in it, is by the heat of a furnace readily converted into glass; and that although the shore be small, the sand is inexhaustible.

The time when glass was discovered is unknown. Herodotus and Diodorus Siculus relate that the Ethiopians formerly inclosed their dead bodies in glass, and that the ancient Egyptians made glass of a dark colour in imitation of that manufactured in Ethiopia. But their magnificent cups evince a considerable knowledge in the art of making glass; and of which the Emperor Hadrian, then residing at Alexandria, thus writes to the consul Servius: "I have sent to you," says he, "some Alassian cups of various colours, given to me by the priest of the temple. They are dedicated to you, and particularly to my sister; and I desire that you will always produce them at your feasts on holidays."

Several ancient writers relate, that, in the reign of Tiberius, an eminent Roman architect acquired great celebrity from the manner in which he had repaired a large portico in the city, which was giving way and seemed likely to fall; and that on account of his popularity, or some other such cause, the emperor banished him from Rome, forbidding him ever to return again.

⁵ Pliny, lib. v. cap. 19.

⁶ *History of the Wars of the Jews*, book ii. chap. 9.

⁷ *Ibid.* book ii. chap. 17.

This individual, it is further stated, when in banishment, made experiments on glass, and, having discovered a mode of rendering it malleable, ventured again to Rome and found means of presenting one of his glasses to Tiberius, in the hope of not only being pardoned for returning without leave, but having his sentence altogether remitted; and that, on the contrary, the emperor was displeased at the invention, supposing that it would tend to lower the value of gold; and having learned from him that no one was acquainted with the method but himself, he ordered his head to be immediately struck off, that the dangerous secret might not transpire¹. Pliny relates, that an artist who had acquired the art of making malleable glass, had his house destroyed by the enraged populace.

Blancourt asserts, that an ingenious Frenchman, in the reign of *Lewis the Just*, also discovered the art of making malleable glass, and that he presented a fine image or bust, made with such glass, to the Cardinal Richlieu; who, foreseeing the injury which such an invention would do to the glass manufacture, ordered the artist into perpetual imprisonment².

We read of glass-houses being in use very early in the city of Tyre: and there is reason to believe that great part of the known world was at one time supplied with glass by the Tyrians, though it appears uncertain whether the great manufactories were in their city or in Phœnicia, as before mentioned. It has also been said, that glass-houses were erected in Great Britain before it was visited by the Romans.

It is very uncertain when glass was first employed for the transmission of light and other optical purposes, or how long any of the nations of Europe have enjoyed the benefit of glass windows. The best buildings in Herculaneum had windows made with a sort of transparent talc³.

One of our oldest English historians, Bede, tells us that in the seventh century it was not known how to make window glass in England; and that in the year 674, the Abbot Benedict sent for artists from abroad to glaze the church and monastery of Weremouth in the county of Durham. These men came probably from Venice; for the first glass that was manufactured in Europe was made there. Loysel thinks that the emigration of refugee artists of Phœnicia to Italy brought the glass trade first among them⁴. We learn also from Bede that the agents of the Abbot

¹ Dion Cassius, *Hist. Rom.*, Isidorus, and Petronius Arbitr.

² Blancourt's *Art of Glass*, p. 15.

³ See an Account of the Antiquities of Herculaneum translated from the Italian by Messrs. Martyn and Lettice, in quarto, with engravings.

⁴ *Essai sur l'Art de la Ferrerie, Discours Préliminaire*, p. 3.

“brought several glass-makers with them when they returned, who not only performed the work required by Benedict, but instructed the English in the art of making window glass for themselves, also glass for lamps, drinking-vessels, and other uses⁵.”

Notwithstanding the interest which so important an application of glass was likely to occasion, it is probable that glazed windows were not common in these kingdoms until several centuries after the period above mentioned. Dr. Henry says positively, that although the art of making glass was introduced in the seventh century, it was afterwards so much neglected, that no private house had glass windows till after the conclusion of the tenth century⁶. Before that period the windows of houses and even of cathedral churches admitted the light through fine linen cloths or lattices of wood⁷.

To prevent the surprise that may be occasioned to some persons, by the assertion that glass windows are comparatively but of late introduction in Europe, it may be remarked, that there are some countries on the face of the globe which have never yet enjoyed this luxury. This is the case at present at Rio-de-Janeiro in South America; for a friend of mine, who is largely concerned in the manufacture of glass, sent a considerable quantity of window glass cut into panes of different sizes, to that country, when the court of Portugal removed thither, in expectation of making a great advantage of it: but, when it arrived, the captain of the vessel had the mortification of learning that there were no window-frames in any of their houses, and consequently the glass would be useless. The glass was therefore sold for embellishing the images of the saints, it being customary to decorate the walls of every house with such images and statues with glass before them, something in the way in which stuffed birds are preserved in this country.

It would seem that glass had not been long in common use for windows, or for the mere transmission of light, before the Monks became desirous of decorating it with ornamental paintings; for the art of painting on glass was brought into this country in the early part of the thirteenth century, during the reign of King John⁸; it having been practised in France some time before that period, and must then have arrived at a considerable degree of perfection, for it appears that the windows in the Abbey of St. Denys were painted in the twelfth century. The subjects of these paintings were the representation of the first Croisade, in

⁵ See Bede's *History of Weremouth*.

⁶ Henry's *History of Great Britain*, 8vo, vol. iv. p. 118.

⁷ William of Malmesbury *De Gestis Pontific*, p. 149.

⁸ Walpole's *Anecdotes of Painting*, p. 5.

ten different compartments, of which the engravings may be seen in Montfaucon ¹.

So late as in the thirteenth and fourteenth centuries, the houses of the lower classes in England had not glass windows. Nor is it improbable that such windows were thought very magnificent even in churches; for Chaucer, who wrote towards the latter end of this period, in describing the dress of his parish clerk Absalom, says that the upper parts of his shoes were cut in imitation of the church window ².

It is generally understood, that the houses in Italy were the first in Europe that were decorated with glass windows; that the custom was adopted in France soon afterwards; and that the French nation enjoyed that luxury a considerable time before England availed herself of the improvement.

Even now, in some of the least civilized parts of the Russian Empire, a kind of laminated gypsum called *lapis specularis*, found in abundance in that country, is used in windows as a substitute for glass.

Coloured glass, or glass stained during its manufacture, was known to the ancient Greeks and Romans; but it is only of late years that the English artists have acquired a knowledge of this process. Dugdale informs us, that when the citizens of London in the reign of Henry V. undertook to beautify St. Paul's, one John Prudde, a glazier in Westminster, engaged to glaze the chapel "with glass from beyond the seas, of the finest colours, of blue, yellow, red, purple, sanguine, and violet, and of all other colours that shall be best to embellish the matters, images and stories that shall be delivered to him, by patterns on paper, in rich colour, at his charges ³."

From this testimony it appears that glass in considerable quantities was made on the continent of Europe earlier than in this country. In Bohemia glass is now made to a very great extent. There are even many towns that are dependent upon this manufactory, and the Continent is chiefly supplied by these artists. Their practice is to fix upon a large wood, and cut down timber enough to allow them room to build. With this timber they erect a wooden house, together with sheds and warehouses; they then dig for clay to make the furnace: when this is ready they cut down timber for fuel, and from the ashes of the fuel and those of the brush-wood they prepare the alkali for the use of the manufactory. When the wood is cleared, and their fuel exhausted,

¹ Montfaucon, *Les Monuments de la Monarchie Française*, folio, Paris 1729, tome i. p. 384.

² Chaucer's *Works*, p. 26.

³ Dugdale's *Antiquities of Warwickshire*, vol. i. p. 446.

these buildings are pulled down, and the workmen remove to another district.

The Government of France, in the early part of the fourteenth century, took great pains to improve the manufacture of glass, and ordained that none but gentlemen or the sons of the nobility should be allowed to exercise the trade, or even to work as artificers in the manufactories of this most highly esteemed commodity. In consequence of this injunction, a company of persons of this description was incorporated, and obtained many important privileges and immunities from the state, particularly that of being allowed to work at this curious art without derogating from their nobility. It is indeed asserted, by the writer who is the best authority we have on this subject, that there never was an instance of any one being attainted to whom these privileges had been granted; for they conducted themselves so irreproachably, that their honours were invariably transmitted inviolate to their posterity⁴.

It was, probably, the success of the Venetians in this elegant art which induced the French authorities to interest themselves in promoting its establishment; for it appears that, in the thirteenth century, these people had established a manufactory of large glass mirrors at Murano, a populous village within one mile of Venice, where mirrors of such an uncommon size were made that they astonished all Europe. Henry III. King of France, when visiting Venice, was so charmed with the work of the artificers at Murano, that he ennobled both them and their posterity⁵.

In the year 1453, Anthony de Brossard, Lord of St. Martin and Prince of the blood royal, finding the business of glass-making to be so considerable, and knowing that it did not derogate from nobility, obtained a grant from the Prince to establish a glass-house in his own county, with prohibition of any other; and, in consequence of this, the elder sons of that family continued uninterruptedly to exercise the art till the latter end of the sixteenth century, when the proprietor was killed while commanding a troop at the siege of Chartres. Some time before this period, the Messieurs de Caqueray, gentlemen of ancient extraction, procured the right of glass-making by an alliance in marriage which one of their ancestors in the year 1468 contracted with a daughter of the Lord of St. Martin above mentioned, who gave up half of his right to the monopoly of glass for part of her marriage portion.

⁴ Blancourt's *Art of Glass*, p. 28.

⁵ Busching's *Geography*, vol. iii. p. 83. Misson's *Voyage to Italy*, vol. i. pp. 300 & 301.

This grant was afterwards confirmed in the Chamber of Accounts of the French Government¹.

On the death of Anthony de Brossard, the younger sons of his family undertook to carry on the art, and continued it for more than a century. Whether the trade continues still in the same line, I have not hitherto been able to ascertain.

An ancient family of the name of *Vaillant* also obtained the grant of a glass-house as a recompense for their valour and public services, together with a poignard d'or, on azure, for their arms. Mr. Blancourt, who long resided in France, likewise notices that, at the time he wrote, they had many other great families among them, who were descended from gentlemen glass-makers that had declined following the art, and that some of these had been honoured with purple, and with the highest dignities and offices in the state.

Here it may be observed that the art of grinding and cutting glass for ornamental purposes was not practised till about the beginning of the 17th century. The inventor is said to have been Caspar Lehmann, who obtained in the year 1609, from the Emperor Rodolphus II., the title of "Glass-cutter to the Court²." The art of engraving on glass by fluoric acid was introduced by Henry Swanhard, an artist of Nuremberg, in the year 1670³.

The glass made in France had never been equal to that fabricated in Italy. But while the great Colbert was Minister of that country, a fortunate event enabled that eminent man to lay the foundation of this manufactory in the way which they had so long desired.

Certain French artists, established at Venice, found means to obtain at Murano an exact knowledge of the processes employed in the fabrication of plate glass, and they returned to France with the hope of enriching their native land with that splendid branch of art and of commerce. The Minister received them graciously; and, having empowered them to select such a situation as they might deem the best suited to their undertaking, they established themselves in the year 1665 at Tourlaville, near Cherbourg⁴. This Company afterwards obtained a patent for making plate glass, and an advance of 12,000 livres for four years was granted them by the French Government.

In the year 1688, Abram Thevart, an ingenious manufacturer, made a proposal to the Court for *casting* glass mirrors, and engaged that they should be of a larger size than any ever before

¹ Blancourt's *Art of Glass*, p. 30.

² Beckmann, vol. iii. p. 223.

³ Nicholson's *4to Journal*, vol. iv. p. 1.

⁴ Loysel, *Discours Préliminaire*, pp. 5 & 6.

made⁵. This individual obtained likewise a patent to continue for thirty years; and the first plates which he cast⁶ were made at Paris, and were of the extraordinary dimensions of 84 inches by 50 inches, a size which surprised all the artists of that day⁷.

Notwithstanding this success, not more than three years elapsed before these proprietors found it expedient to remove their establishment to St. Gobin, in the department of the Aisne; and there they laid the foundation of a manufactory which is still in a flourishing condition, and is perhaps the most important one of the kind which is yet in existence.

In these stupendous works, plates for mirrors are now made of the vast size of 105 inches in height by 60 inches in breadth; and when they have been properly annealed they are conveyed to the Gobelins in Paris to be polished⁸. The double convex lens which I have described in the Essay on Temperature, page 43, was made in the same manufactory. The instrument described above has been broken, and the Government have since caused to be fabricated at the same manufactory a massive plate of 2 metres diameter by 0·067 in thickness, weighing 500 kilogrammes; the largest piece of workmanship in glass that was ever executed, being in English measure $2\frac{1}{2}$ inches thick, 6 feet 6 inches in diameter, and weighing eleven hundred pounds avoirdupois.

It is now time, however, for us to look into the progress of this manufacture in England. The method of working in glass, as we have already seen, was introduced here so early as the seventh century; but I am inclined to think that for many ages our artificers made no improvement whatever in this curious art. Their business was probably confined to the manufacture of coarse window glass, and the most rude kind of culinary and drinking vessels.

Nevertheless, about the middle of the sixteenth century this country began to acquire eminence in the manufacture of glass, of which we have abundant evidence: thus in the year 1575 one of the London glass-houses was destroyed by fire; and Holinshed, speaking of it, says, "The same house which had consumed great quantities of wood in making *fine drinking-glasses* is now itself consumed⁹."

Manufactories of considerable consequence were afterwards established at Crutched Friars, and in the Strand, London; and these were much encouraged by King James I. and Charles I.,

⁵ Mirrors of glass were attempted to be made in the ancient glass-houses of Sidon; but the artists could not succeed in the attempt. Pliny, lib. xxxvi. cap. 26.

⁶ A very interesting and instructive paper on the antiquity of metallic mirrors may be read in Beckmann's *History of Inventions*, vol. iii. p. 164.

⁷ Savary *Dict. de Commerce*, tome iii. p. 87. Beckmann, vol. iii. p. 216.

⁸ Busching's *Geography*, vol. ii. p. 398. ⁹ Holinshed's *Chronicle*, p. 1261.

who both prohibited the importation of all foreign glass, excepting that of the most inferior kinds ¹.

The former of these monarchs, as an expedient to raise money without the aid of Parliament, granted to Sir Robert Mansel an exclusive patent for making glass, and allowed it to be given out, that this monopoly was afforded him in consideration of, and as a reward for, his having substituted pit coal for wood in its manufacture; and that on the same ground he should be allowed the exclusive privilege of importing drinking-vessels and every other article of glass from Italy, which could be made there of a finer quality than had at that time been produced in England ². Common pit coal is however the fuel which is now employed throughout England for making all kinds of glass.

In the reign of King Charles the Second a Mr. Ravenscroft very materially improved the manufacture of flint glass. He is said to have made all kinds of glass drinking-vessels of a quality fully equal to any that were then manufactured abroad.

The Duke of Buckingham, who had brought workmen from Venice for the purpose, was likewise the means of establishing, about the year 1670, a considerable work at Lambeth for the manufacture of fine *plate glass* ³.

Thus by degrees was the manufacture of every kind of glass introduced into this country; and the trade made such rapid progress amongst us, that in the year 1696 there were no less than ninety glass-houses in different parts of the kingdom. Of this number twenty-four were in London and Southwark, seventeen at Stourbridge, eleven at Newcastle-upon-Tyne, and nine at Bristol. The rest were dispersed in those other counties of England where coal is readily procured. Of these different manufactories forty-two were called Bottle-houses, or such as were chiefly employed in making the common black bottles; five were employed for crown glass; twenty-seven for flint, green, and other ordinary glass; two in making plate-glass for mirrors, &c.; and fourteen were exclusively appropriated to the manufacture of window glass.

We may naturally suppose that such a variety of establishments would give a permanence to any manufacture. This has really been the case; for, at this day, the art of glass-making has become one of the staple manufactures of our country.

It has already been shown that there are five different kinds of glass-houses in this kingdom; but before we attempt to describe any of the operations which are performed in them, it will be ne-

¹ Rymer, tome xix. p. 663.

² Campbell's *Political Survey of Great Britain*, vol. ii. p. 28.

³ Houghton's *Collections on Husbandry and Trade*, vol. ii. p. 43.

cessary to enumerate them afresh, as they are now rather differently distinguished from what they were a hundred-and-twenty years ago, the time of which we have just been speaking.

The English glass-houses are now known by the names of the *Crown* or *Window* glass-house; the *Broad* glass-house; the *Bottle*-house; the *Flint*-house; and the *Plate* glass-house. The glass trade of Great Britain has indeed become so considerable, that in general there are separate and distinct establishments for each of these species of glass. I know of no instance of the same proprietors being concerned in more than one or two of these different branches of glass-making.

It will be most convenient, however, and the nature of the whole manufacture will probably be better understood, if we begin the account of the different manipulations, by a description of the method which is adopted in making *flint* glass.

A very small quantity of nitre, of manganese, and of white arsenic, is added to 3 cwt. of Lynn sand, 2 cwt. of red lead, and 1 cwt. of pearlash; and when these materials have been well mixed, the whole are combined with about one-fourth of their weight of old broken flint glass. These proportions are frequently a little varied, each manufacturer having his own ideas and peculiar practical knowledge on the respective properties of every ingredient.

It should however be mentioned, before we proceed, that some houses, instead of Lynn sand, use a very white sand, from Alum-bay in the Isle of Wight, and others procure it from Maidstone in Kent; and that the pearlash is always previously purified for this purpose. The following is the process:—First, it is dissolved in water, and suffered to remain some time undisturbed, to allow the impurities and contingent matters to subside; after this the clear solution is submitted to the action of heat, to expell the water and to reduce the alkali again to a dry state. One hundred weight of *first* American pearlash is thus generally reduced to 70 or 80 pounds.

The materials being mixed, they are then, by a few shovels full at a time, cast into the crucible, previously brought to a white heat; and as these melt, more is thrown in until the pots or crucibles are all full, care being taken that the same temperature is continued till the ingredients are thoroughly united, and the whole formed into a perfectly transparent glass. The operation requires generally from 20 to 30 hours.

Flint glass is known to be perfect when the silica is all dissolved, and the paste is entirely free from sand specks and air bubbles. This however is never the case till the highest point of heat is attained, and the *metal* (a technical term of the workmen for glass in a state of fusion) has become sufficiently fluid to allow of the

carbonic acid gas and other volatile matters to rise freely through the mass and escape. It is usual to ascertain the purity of the glass, by taking out a few ounces and blowing it into the shape of a long pear, with a small cavity within. This when cold is inspected, as a kind of proof or sample of the state of the glass in fusion.

When the glass is found to be completely formed, the workmen dip their instruments, which are long hollow tubes of iron, into the melted metal, and, turning them about several times, they collect, on the point of the instrument, as much of it as they require for any particular purpose which they may have in view. Then, by blowing with the mouth and rolling the hot metal upon a smooth horizontal iron plate, they form it into any shape that may be desired, such as glasses, decanters, phials, &c.

This part of the process is extremely interesting and even captivating to those who have never before seen the operation; for, without inspecting, no one can form an adequate idea of the facility with which the workmen form all sorts of vessels and instruments of this very curious and valuable material.

As it may be difficult for some persons who have not seen a glass-house to conceive how so much glass in the state of melting, as is necessary for making a large vessel, can be taken up on the end of an iron tube, it is proper to state, that every time the workman dips the instrument into the crucible of melted glass he exposes it a moment to the current of air, which chills the surface, and enables another portion of metal to attach itself to the former; and this he repeats till he has collected a quantity sufficient for his purpose.

In the large houses, many workmen are constantly employed both day and night, because it is necessary that the work should go on without intermission, till all the metal in the furnace be exhausted. Each of these men has a boy to attend him; and these children are perpetually employed in carrying the articles, the moment they are made, one by one, to the *lier* or annealing furnace, where they are kept for many hours, in order that they may cool gradually.

The *lier* is a very long heated chamber, furnished with many shallow iron pans, called *lier-pans* or *fraiches*, for holding the goods; and these are moved further and further from the fire by means of a set of pulleys and a windlass, till they are brought to the other end of the gallery, where the temperature is so much reduced, that in general the articles are all sufficiently cool to be taken out with safety.

I observe, in passing, that the term *lier-pan* is perhaps derived from the French word *lier*, to bind or knit together; from an idea that the glass was not completely formed, or its particles

properly united, until it had gone through the process which we now call annealing; and that the word *fraiches* is derived probably from the French *fraiche*, cool, or *refraichir*, to cool.

This process of annealing is absolutely necessary for the production of perfect glass, whatever may be the kind, or whatever the form of the article which is made with it. Hence it may be understood why glasses often break without any apparent cause; for, whenever this happens, it may be attributed to imperfect annealing, unless one side of a piece be more exposed than the other to heat or cold; for then it will inevitably crack, because glass is a worse conductor of heat than any manufactured commodity with which we are acquainted. This property of glass being a non-conductor of heat, is often exemplified in a curious manner in the glass-house. The following is a case that may be mentioned. When a crucible full of liquid glass breaks by accident, a large tub of water is brought to the mouth of the oven, and the fluid metal is laded with all possible expedition into it, to prevent its running into the furnace and being lost among the ashes. When this large mass of glass has been some little time in the water, its surface will become nearly cold, while the centre of it will be red hot, and continue so for several hours after the outside has been cold enough to be handled with safety.

Having thus given a brief account of the method of making flint glass, it may be remarked, that either of the fixed alkalies, with a due proportion of flint or sand, will, without any other ingredient, make a pure and transparent glass. A century ago the best glass was always made from ground flints: hence it was that white glass acquired the name of *flint glass*; but when it was discovered that good sand is nearly all siliceous earth, this was substituted for flints.

The other materials, viz. the lead, manganese, nitre, and arsenic, are therefore added with different intentions; and the proportions which are noted above are sometimes varied, for the sake of producing a glass of a quality different from that which is usually made.

Thus, the lead is employed with the design of giving a greater degree of fusibility to the silica, to add weight to the glass, to enable such of it as is designed for ornamental work to take a higher polish, and to render it less liable to break by sudden changes of temperature.

Besides the several uses of lead which I have enumerated, it has another effect upon all ornamental flint glass, which is of great importance; for it has the property of increasing the refractive power of the glass; and hence we are enabled to decompose the solar rays of light, by means of a glass prism, into what are

called the prismatic colours. Lead is a simple combustible, and so are the diamond and hydrogen. It was Sir Isaac Newton who first suggested that the diamond, from its refractive power, was of a combustible nature, and that water also must have something in its composition that would burn, as it breaks the rays of light. Thus can we account for the superior beauty of the English flint glass. Plate-glass possesses no such brilliancy.

The employment of oxide of lead in the manufacture of glass is very ancient. In the collection of antiquities at St. Denis, an ancient mirror was shown which was said to have belonged to Virgil. It was an oval glass, 14 inches in length and 12 in breadth, and weighed 30 pounds. This was found on analysis to consist of artificial glass, mixed with a considerable portion of lead.

To explain the use of the other ingredients, it may be said that the manganese and the nitre are of service in destroying whatever carbonaceous substances may be in the mixture. The white oxide of arsenic is also used with the same intention. But this is seldom employed now, except where the manager suspects that the materials have been either not sufficiently purified, or that the calcination had not been properly conducted; each of these articles having the property of abstracting the carbon, and dissipating it in the form of carbonic acid gas, leaving the glass whiter and more transparent. There is however some nicety always required in the use of the oxide of arsenic; for, though it makes the glass whiter, it will give it an opake or rather an opal appearance, if too much of it be employed. Some manufacturers of flint glass have discontinued it altogether, because they conceive that the lead renders the arsenic too volatile to be of much service.

The next species of glass to be described is that which is known in the trade by the name of *crown-glass*, being in fact the best sort of window glass which is made in this country.

The apparatus employed in the manufacture of CROWN-GLASS are, a reverberatory furnace for calcining the materials; a large furnace containing the pots or crucibles for melting these materials and forming them into glass¹; and other furnaces for heating or annealing the crucibles, previously to their being employed. Besides these, there are others which contain no crucibles, but are merely employed for re-heating the metal time after time, to enable the workmen to keep it sufficiently ductile for being thrown into such forms as they require. The *bottoming-hole* and the *flashing-furnace*, as they are called, both come under this description. There are many other technical terms in this business: but they are all formed either from the Italian or French language,

¹ One of these furnaces generally takes four or six pots; and these are so large, that some of them are capable of holding more than a ton weight of glass.

glass having been long made in those countries, and it was from them that this art passed into the other states in Europe.

The materials which are employed in making the best crown glass, are six bushels of fine Lynn sand and twelve bushels of Orkney kelp.

These are the usual proportions; but some kelp will vitrify more and some less sand than has been mentioned, because of the variation which there is in the quality of what is called best kelp.

Orkney kelp is preferred for window glass, because it makes it of a better colour than the Western Isle or the Scotch kelp. This is probably owing to the sand of the latter containing more iron. Mr. Bowles, the celebrated maker of crown-glass at Cockhill, Ratcliffe-highway, London, always used Spanish barilla instead of kelp, and his glass was ever preferred to that of others. This gentleman had also an establishment at Vauxhall for making plate-glass: but the concern has been abandoned for more than twenty years, the proprietor having retired with an ample fortune.

It appears to me, that it would be a better practice to dry the materials thoroughly, and then to apportion them by *weight* instead of by measure as above mentioned. By repeated inquiries I have indeed learnt that one of the large manufacturers has adopted this method, and that his general proportions are, 450 lbs. of Irish kelp dried and ground; 325lbs. of Lynn sand dried; and 25lbs. of slaked and sifted lime.

These materials, when thoroughly mixed, are calcined for about two hours in a degree of temperature inferior to that of fusion; the fusion being in some measure prevented by constantly stirring the mass, which occasions a fresh surface to be perpetually presented to the action of the fire, and also favours the escape of the aqueous, gaseous, and other volatile matters which are required to be dissipated by the process. The heat is then increased till the whole becomes pasty; and it is preserved in this state for three or four hours more, constantly stirring the mass during the whole period. The materials, which are still in a soft and pasty state, are at length removed from the furnace, and, advantage being taken of the softened state of the mass, the whole is put very hastily into the form of square cakes, which are known to the workmen by the name of *frit*, the operation itself being called *fritting*. Some years ago I remember to have been very much at a loss to discover why it was necessary to make the glass first into frit, and why it might not be begun and finished by one process; but I now understand that whenever this previous operation is not performed, the alkali is apt to be driven off by the heat of the furnace, before it has time to combine sufficiently

with the silica; whereas, in the operation of fritting, the temperature is powerful enough to effect this, and yet not equal to volatilize the uncombined alkali.

The manufacturers of glass, I trust, will not be displeased at my remarking on a circumstance which is of more consequence than many persons are aware of. From my own experiments, I am warranted in saying that pure alkali evaporates at a lower temperature than is generally imagined. Hence great attention ought to be paid, in preparing the *frit*, not to give it too great a heat, or to remove it from the calcining oven before it be thoroughly prepared; otherwise, the alkali will fly off in vapour instead of combining with the silica. This may be often seen arising as a vapour from the surface of the crucibles in a glass-house furnace. There is on this account an advantage in using *soda* in preference to potash, because soda combines more readily with the siliceous earth.

The manufacturers are desirous of keeping the frit as long as they can; and hence it is that the cakes are seldom employed immediately, but are generally piled up in a corner of the manufactory for future use, it being a prevailing idea, that the frit is better the older it is; and I have been informed that some of the opulent makers have a regular succession of it in store, and never use any that is not twelve months old.

To prepare for making crown-glass, this frit is put into crucibles in the melting furnace; and when the crucibles are filled, old glass is piled upon the frit, as high as it can be placed with safety. The furnace is then made hot, and the heat is regularly increased till it acquire the maximum, at which state it is continued for 30 or 40 hours. During this time the materials become so thoroughly united as to form one perfectly homogeneous and transparent mass of fused metal, fit for the fabrication of sheets of best window glass.

To make this species of glass, the workman commences the operation as he would in the flint-house, already described. He dips the long iron pipe into the melted metal, and by repeated dippings gathers as much of it round the end of the pipe as he knows by experience will be enough to form a table of glass. A *table* is the workman's phrase for a circular sheet of finished window glass. These are generally 4 feet in diameter, and weigh 10, 10½, or 11 pounds each. Twelve of these are called a *side* or a crate of glass.

When the lump of metal is properly attached to the pipe, it is rolled frequently backwards and forwards upon a polished iron table, to change it from a globular to a cylindrical form. The workman then blows down the tube, to which the red-hot piece of glass is attached; and by this means, and a continuation of

the rolling, it becomes expanded into a form similar to figure A, in Plate XIX., and which is called by the workmen a *Parisienne*. He then carries it to the mouth of the melting furnace to heat it afresh, that it may be in a proper state for being further expanded by the breath, till it takes the form described by figure B; when it is immediately transferred to the furnace called the *bottoming-hole*, to be again heated; and this enables the workman to enlarge it, by the mere force of his breath, till it acquire the form described at figure C; after which, by heating it and blowing afresh, it assumes the shape of figure D. The artist having brought it into this latter form, the next object is to affix another working iron to the opposite side of the piece, to enable him to detach with safety the first instrument. The intention of this contrivance will be rendered manifest as we proceed in our description of the process.

To effect this, the workman takes the glass which has been so far modelled, to a table covered with ashes, which are designed to prevent the adhesion of the glass to the table, and also to preserve the glass from too great a reduction of temperature; and while lying there, a supernumerary workman brings another working iron¹, with a small lump of hot metal at the end of it; and this he attaches to the piece of glass under operation, at the letter Y, exactly opposite to Z, the place where the first iron is still united.

Having by means of this small lump of fresh glass attached a new working iron, it becomes necessary to withdraw the former, as before mentioned, and this is effected by the usual expedient. The workman wets the end of a small iron utensil with a little cold water; with this he touches the glass at letter Z, where it produces a crack; then by a smart stroke he detaches the old instrument from it, which leaves a hole in the piece of glass of about two inches in diameter, and which has then the appearance shown by figure E.

A new working iron being now attached to the glass at the point exactly opposite to that where the former one adhered, the workman carries it by the punt² or new rod, to the flashing furnace, and turning it gently in his hand, holds it for a few minutes at the small opening called the *nose hole*. This is a technical name by which these openings are known to the workmen in the North of England. Agricola and other old writers on glass called them *boccas*. This small opening into the large furnace is contrived

¹ This instrument differs from the former, in its not being a tube, but a rod of solid iron. It is called a *punt* or *pontil*.

² These instruments are smaller and lighter than the blowing irons, and consequently more manageable in these latter parts of the process, when it is necessary to make them revolve in the hand with greater velocity.

merely for the purpose of heating that part of the glass to which the cold water had been applied. By this means it is put in a proper condition to be introduced into the larger opening in the same furnace, where it acquires heat by degrees till the operator perceives that the whole mass has again become sufficiently ductile. He then begins to turn it quicker and quicker, holding it the whole time at the mouth of the oven, till it becomes so much softened, that merely by the centrifugal force communicated by the rapid revolution of the iron instrument to which it is attached, and which requires great dexterity on the part of the workman, the whole mass opens itself by degrees, extending further and further till it assumes the forms of *F*, *G*, and *H* in succession; and when it has attained the latter figure, it flies entirely open *in an instant*, as shown at *K*, and becomes one immense circular sheet of glass, 48 or 50 inches in diameter, and of one uniform thickness. It was formerly thought to be a great acquisition to be able, by this process, to make a perfect table of glass four feet in diameter; but I understand that Messrs. Attwood and Smith, of Gateshead in the county of Durham, are enabled to produce tables of five feet, which are the more valuable, as they yield larger squares than were ever made, except in plate glass; and the quality of it is of the best kind. The centre of the table of glass, where the punting iron was attached, is of course somewhat thicker, and is known to the workmen by the name of the *bull's eye*. Notwithstanding this, it is curious to observe how very uniform in thickness all the rest of the plate is.

This account of the varied manipulations is presented to my readers in considerable detail, together with drawings of the glass in every stage of its progress¹, because I believe the production of this peculiar species of glass to be one of the most curious and interesting processes which any of the manufactures of this or any other country can exhibit. The tenacity of heated glass is shown in a very striking manner by this operation; for though the plate be 50 inches in diameter, and not more than a line in thickness, it bears to be revolved in the hands of the workman with considerable celerity; and when it changes by its centrifugal power from figure *H* to figure *K*, it expands with a force sufficient to dash it, if it were cold, into ten thousand pieces. The workmen assured me that this circumstance never fails to arrest the attention of every visitor.

When the crown-glass is thus finished, the perfect plate is removed into the annealing arch, and there placed on its edge that it may become properly tempered by gradual cooling, as is practised in the manufacture of every sort of glass. It is a very nice

¹ See the engraving prefixed to this Essay.

point to regulate the temperature of the annealing arch, for a small excess of heat would render the plates so soft that they would bend out of the perpendicular and be much injured: on the contrary, if the furnace be not hot enough there is great danger of the plates flying in pieces, though if this should not happen the defect would inevitably be discovered by the glazier; since glass so imperfectly annealed is operated upon by the diamond with great difficulty, and it is almost impossible ever to cut it with exactness.

In the fabrication of crown-glass, nothing is of more importance than to keep the melting furnace at its full heat during the whole time of the operation; for, whenever the men fall asleep, which they are apt sometimes to do, the heat of the oven gets checked, and it is almost impossible to bring it again to the former temperature.

This arises from the peculiar property which glass possesses, of being a slow conductor of heat; and, unfortunately, the further the glass is advanced towards perfection the greater will be its liability to damage from this cause; and therefore the more solicitous should the manufacturer be, to watch this part of the process. This accident is of such frequent occurrence, that it alone has been the chief means of occasioning crown-glass to be divided into four classes, viz. firsts, seconds, thirds, and fourths; between the two extremes of which there is a difference of 50 per cent. in price. Indeed, if the excise duty be put out of consideration, the glass of the fourth quality nets the manufacturer less than half the price of the first. In one of the largest crown-houses which I have seen, where they make 1800 tables or 150 sides per week throughout the year, they consider one-half to two-thirds of this quantity to consist of seconds and thirds. When the firsts were sold at 6*l.* 10*s.* per side, the thirds brought only 4*l.* 18*s.*, the duty being paid by the maker.

The next species to be described is BROAD-GLASS, or inferior window glass. This is quite a distinct manufacture from that of crown-glass, and the process of fabricating it is also totally dissimilar. The materials which are employed, and the method of conducting the operation, are as follow:

Six bushels of soap-boilers' waste, three bushels of kelp, and four bushels of sand are mixed together and cast into a calcining furnace. But there is no absolute rule for the proportions, because the two first of these materials are as variable in their qualities as can well be conceived, and therefore the operator is always guided by his own judgement in apportioning the respective quantities, and nothing but practice can direct him.

I have not found that the proprietors of those houses where

broad-glass is made lay any stress on the fineness of the sand; but this is certainly an important circumstance. Loysel has stated, as the result of his own experience, that if coarse sand be used, 2lbs. of pure alkali must be put to every 4lbs. of sand, or it will not melt; whereas if the sand were very fine, 1lb. of pure soda would be sufficient. Hence it follows, that there remains in the finished glass, as a constituent part of its substance, only one half of the alkali at first employed. The other half is dissipated during the process, and entirely lost.

The process of calcining the materials requires from twenty to thirty hours, and is designed to burn off all the inflammable and heterogeneous matters which would spoil the colour of the glass, as well as endanger its boiling over when it came into the melting furnace. It is observable that the materials are not suffered to melt while in the calcining furnace, but are kept at a great heat and stirred very frequently with an iron rake, which facilitates the separation of the gas, and completes the combustion of all such contingent matters as are capable of this change.

When the mass has been thus properly calcined, it is removed with iron shovels while red hot, and carried to the melting furnace, where the pots are entirely filled with it; and in the course of twelve or fifteen hours of exposure to a due degree of heat, the whole will become perfect glass. To form this into sheets, the following method is pursued:

The glass is withdrawn from the pots by iron tubes in the way already described for the flint- and crown-glass, and it is blown into globes, or rather into hollow cones, of about a foot diameter. It must be recollected that all glass, the large plate-glass excepted, whatever be its form, whether that of an electrical tube, a goblet, a decanter, or a sheet of window glass, is fashioned from a hollow sphere produced by the action of the breath. That is, a piece of fluid metal is first blown into a hollow globe, and then it is moulded by the workman into the desired shape. When these globes are formed, they are carried again to the mouth of the oven, and while there, one side is touched with a cold iron dipped in water. This produces a crack, which runs along it longitudinally in nearly a direct line. When this crack is produced, the cone is opened upon a smooth iron plate fixed at the mouth of the furnace, and it then forms a sheet of thin transparent window glass in a shape somewhat like that of a fan. In a few minutes this becomes hard enough to admit of being removed to the annealing apartment, that its temperature may gradually diminish. This species, which is, probably, the first that was ever manufactured for the use of windows, is called *broad* or *spread* window glass, to distinguish it from what is termed the crown-glass.

Another kind not yet described, is a green glass, known to the trade by the name of BOTTLE-GLASS, and the works at which it is manufactured are called *bottle-houses*.

To make this species they take three bushels of soap-makers' waste ashes, and one bushel of coarse river sand. Sometimes a portion of kelp is also added, but this is not used in all manufactories. These materials are calcined either in a distinct furnace, or in arches attached to the furnace of fusion, where they are kept at a red heat for twenty or thirty hours. From thence the mixture is removed, still of a red heat, to the melting furnace, where by means of iron shovels the pots or crucibles are filled with it, and an intense heat is again applied. By continuing the materials in this high temperature for twelve, fifteen, or eighteen hours longer, they become perfectly fused and converted into a true glass, fit for making wine bottles, garden bell glasses, chemical retorts, aquafortis carboys, and any other large vessels for chemical laboratories or other purposes.

These articles are all fashioned by a method similar to that which has been described under the article flint glass, excepting half-pint, pint, and quart bottles, which are blown in a *mould* either of iron or brass. These goods are likewise removed, while yet very hot, to the annealing furnace, for the purpose already mentioned in describing the other species of glass.

The bottle metal is peculiarly fit for making chemical carboys, as it bears the action of all the mineral acids without sustaining any injury; whereas flint glass, which is usually made with a large portion of lead, is very unfit for any chemical purpose that requires much heat. Bottle-glass, which is always made without lead, will bear a greater heat without melting, and therefore is much better adapted to many of our operations.

A few observations now present themselves as necessary to be offered on the process of bottle-glass, before we proceed with the remainder of our subject.

The soap-makers' residuum contains a very great proportion of *carbonate* of lime, which is better for this purpose than lime itself, inasmuch as it helps to decompose the sulphates of soda and potash, which are always contained more or less in soap waste, as well as in kelp and the other alkalies of commerce.

There must be a great loss in using the sand in its coarse state, for the reasons already assigned. In some glass-houses on the Continent it is usual to heat the sand red hot, and then throw it suddenly into cold water, in the same way as the potters treat their flint to break it into smaller grains. Why might not our manufacturers, where coal is cheap, adopt this practice? If pains were also taken to wash the Woolwich sand repeatedly in several

waters, the colour of the glass made with it, would, I conceive, be much improved.

Government will not allow the makers of this species of glass to use any but the commonest river-sand, lest the glass should be too good, and the revenue be defrauded by its being applied to purposes for which the best glass is generally used, and which pays a higher duty. The greatest proportion of the sand which is used in bottle-glass is obtained from the river Thames at Woolwich.

I have reason to believe that at most of our English bottle-houses, the calcining is conducted in arches communicating with the furnace in which the metal is founded. In those houses which I have seen there is an arch at each corner of the main furnace, and in these arches the materials remain not only the whole time of founding the former parcel of glass, but also during the time of its being worked up into bottles, &c. which is generally 10 or 12 hours more. Care is taken at the latter part of this period to bring the calcined mixture in the arches to such a temperature, that it may be moved immediately from thence into the hot crucibles without danger of breaking them.

In the neighbourhood of Newcastle-upon-Tyne, bottle-glass is made very profitably from a mixture of lime and sea sand, the mass having been first repeatedly wetted with salt-water. Where glass is thus attempted to be made without any alkali, except what is contained in the muriate of soda, lime is absolutely necessary; for this earth when in conjunction with silica seems in a high temperature to have the power of decomposing common salt.

The preference which is given to the Orkney kelp, may, I suspect, be accounted for on similar principles. This species of kelp contains usually 2 cwt. of lime in every ton, produced from the incineration of the sea shells which are entangled in the weed, and this lime is useful in decomposing the muriate of soda which is always contained more or less in every kind of kelp.

The only species of glass which now remains to be described is that of PLATE-GLASS. Of this there are two kinds, viz. the one made by blowing and opening, somewhat similar to the mode of making the spread window-glass already described; the other is produced by casting upon a table in a way something like that of forming sheet lead. Plate-glass of a considerable size may be made by the first of these methods, but the largest mirrors can only be made by casting. Much of the small plate is consumed in the navy and by merchant vessels for glazing the cabin win-

dows, as no other kind of glass can be depended upon in rough weather.

There are, I believe, only two establishments throughout the united kingdom for the fabrication of plate-glass. The first and most considerable is at Ravenhead in Lancashire, where the largest plates in the world, and inferior to no foreign plates, are made, and these are produced by casting. The other is at East Smithfield, London, where the work is performed by blowing.

I express myself in this decided manner respecting the work at Ravenhead, in order to counteract the declaration of an eminent French manufacturer, who has thought proper to publish the following statement:—"All that the English glass-houses do, may," says he, "be executed, and in fact is executed, with more facility in ours. But they are obliged to give up to us the fabrication of *plate-glass*, and of our fine light glass, made with pure saline fluxes."—*Loyzel*, page 86.—Those who have seen the superb collection of English plate-glass which is constantly on show at Blackfriars, will be not a little surprised at the unqualified nature of this assertion.

In the formation of good plate-glass, the first consideration is that of preparing the soda, this being the species of alkali which is usually employed, and, I believe, from sound reasoning, always preferred for plate-glass. To procure the soda for this purpose, muriate of soda (common salt) is decomposed by means of sub-carbonate of potash, both salts being in a state of solution and assisted by heat. After this, a portion of the muriate of potash is separated from the solution by priority of crystallization, when the remaining alkaline solution is boiled to dryness and reserved for use. Formerly kelp-ashes and even weed-ashes were employed, without any previous lixiviation, in making plate-glass. Consequently the glass was then coloured, and not so brilliant as the modern. In the great work at St. Gobin they used nothing but wood-ashes for many years.

After the alkaline salt has been prepared as above, it is in some measure necessary to analyse it, with a view to ascertain how much real alkali is contained in it, and hence how much sand such a salt will require. When this is known, the calculation is made without difficulty; for it has been found that one pound of pure soda is sufficient for four pounds of sand; and if this quantity of sand be employed, a hard compact glass will be produced that cannot be injured by the action of water, or even any of the common mineral acids. But where so large a proportion of silica is used, it is necessary to employ a heat not less than 18,000° of Fahrenheit, it having been determined that silica is dissolved by alkali in proportion to the height of the temperature at which the founding is conducted.

On the principle that one pound of soda, free from every impurity, will be sufficient for four pounds of sand, then, if the prepared alkali should contain 40 per cent. of real soda, which is about the usual quantity, the remainder being muriate of potash, carbonic acid, and water, the operator would take 160 lbs. of sand to every 100 lbs. of such salt. Upon these data, therefore, the following proportions of the materials will produce a glass suitable for the best plates:—

	lbs.
Lynn sand, previously well washed and dried . . .	720
Alkaline salt prepared as above	450
Quick-lime slacked and sifted	80
Nitre	25
Cullet, or broken plate-glass	425
	1700

These quantities of the different materials are required to produce one pot of metal; and if the process be well conducted, this will make 1200 lbs. of good plate-glass. This will, however, depend in some measure on the size of the establishment. Loysel has given a detailed account of the principal dimensions of the French houses for making plate-glass, and has introduced it by saying that those proportions have already served as a model in several glass-houses, and that experience has justified his opinion of their goodness.

Dr. Merret calculates that 1 cwt. of sand yields 150 pounds of glass. This produce is, however, greater than can be realized, if the founding be properly conducted.

The whitest sand which I ever saw is found in the Isle of Wight, at Alum Bay, very near the Needles. I suspect this would make finer glass than the Lynn sand above mentioned. The importance of pure sand for the manufacture of glass has been acknowledged for many ages. For more than a thousand years before the commencement of the Christian æra, the sand found on the shore of Belus, a river in Phœnicia, was reckoned the only kind fit for making glass; and even after the time of Christ it was collected, and taken away by vessels that came annually from foreign countries, as Strabo, Josephus, Tacitus and others affirm.

Lime is employed on account of the property which it gives to glass, of being a better conductor of heat, and consequently rendering it less liable to break by sudden change of temperature; and because such glass cuts more readily by a diamond than that which is purely siliceous. It is important, however, to use quick-lime, and not the carbonate, as the latter occasions so much swelling of the materials as to endanger their flowing over the sides of the crucibles.

The quality of the lime is of considerable importance. Lime

for this purpose has sometimes been made with stone brought as ballast from Gibraltar, and it answered better than the chalk lime in the neighbourhood of London. I am informed, however, that the best lime for the glass business is that of St. Vincent's Rock, near Bristol.

Nitre is very effectual towards depriving the materials of every species of carbonaceous matter; and hence it improves the colour of the glass, its oxygen uniting with the carbon, and forming with it carbonic acid gas, which goes off in vapour. Nitre has also the property of rendering glass more transparent.

The following is the process which has usually been adopted by those makers of glass who prepare their own alkali:—

Any quantity of common salt is dissolved in a boiler of hot water, and nearly double its weight of American or Russian pearl-ash is added to it. This mixture will produce a double decomposition, and two new salts will be produced, viz. muriate of potash and carbonate of soda.

When the liquor in which these salts have been dissolved is concentrated by evaporation to a certain point, which may be easily known by a little experience, the muriate of potash will crystallize; and then the remaining alkaline liquor may be further evaporated till the carbonate of soda be recovered in a dry state. The mineral alkali thus produced may be used instead of purified pearl-ash, in the manufacture of the finest kinds of glass, and the muriate of potash may be sold for the purpose of making alum, for which it is a very suitable salt.

I conceive it might be worth while for a scientific glass-maker to institute a series of experiments to determine whether muriate of potash or muriate of soda, in their entire form, might not be employed to advantage in making some species of glass.

In resuming the relation of the process of making plate-glass, I feel much difficulty in marking out, without being tedious, the exact line of description, so as to render the account in any degree interesting; for I am aware that, were I to enter into all the minutiae of this business, the mere detail would of itself occupy a volume. The following circumstances, however, which all refer to the method of making plate-glass by the process of *blowing*, seem to deserve our attention.

When the materials employed have been sufficiently comminuted and properly united by turning them frequently backwards and forwards upon a floor, the crucibles within the furnace are carefully filled with the mixture, the conciator or founder taking care to have the furnace previously made as hot as possible. Ten hours generally elapse before these materials are totally melted; for during this time the pots are much cooled, and the

fusion checked by the repeated addition of fresh portions of the materials.

“The solvent power of a saline flux upon silica in a state of fusion, is proportioned to the extent of surface presented to its action and the existing force of aggregation. Thus, if a mixture of one part of fixed alkali with two of quartz *reduced to powder*, be put into a crucible exposed for a due time to the heat of a glass-furnace, the vitrification will be complete; but if the quartz be mixed *in lumps* instead of powder, vitrification will only take place on the surface and in strata; a portion of the alkali will be dissipated by the fire, a small quantity of glass will be produced, and there will remain a great portion of the quartz unmelted.”—*Loyssel*, page 18.

The articles being all melted, the next object is to refine the metal thoroughly; and this is effected by continuing the heat at its maximum for several hours longer, till all the neutral salts, the aqueous, carbonaceous, and gaseous matters have disappeared, and the glass is become free from specks or globules of air, and destitute of colour. To describe this state the workmen employ a technical phrase, and say that the metal is become *plain*; and when it is announced that the glass is *quite plain*, they mean that it is entirely finished and quite perfect; whereas in the crown-glass-houses the metal at this stage of the preparation is said to be *fine*, meaning that it is refined or purified by the dissipation of the air bubbles, &c.

When the contents of all the crucibles are brought exactly to this state, a workman goes into the ash-pit, or cave, as it is called, and carefully closes up the openings between the bars of the grate with a composition consisting of clay and cut straw, to prevent the introduction of any air into the furnace through the fire-place, which would endanger the rupture of the pots, and produce too rapid a cooling of the furnace. Some excellent directions for the construction of furnaces, so as to prevent the walls from cracking, are given by *Loysel* in his work on glass.

It is necessary in this stage to secure every opening into the furnace; because when the metal has become *plain*, it is not in a fit state for being worked into plates of glass by the process of blowing; for at this high temperature it would be too fluid to adhere to the irons when dipped into it, or to preserve the shape which it is necessary to give it before it can be converted into a plane surface fit for being made into mirrors. It must therefore be allowed to cool gradually for nine or ten hours after every orifice has been closed, as before mentioned.

The temperature of the prepared metal being thus reduced to the working state, it is modelled in a manner very similar to that of flint-glass, already described. A workman dips an iron pipe

into the crucible, and having taken out a little of the fused glass upon the point of the iron, waits a moment till that has adhered: he then dips it in again and rolls another portion round the former: this he repeats, till he finds he has taken up enough for his purpose. Then, by blowing down the iron tube, he expands the mass of glass a little, and produces a hollowness within it: this he enlarges by repeated blowings till it forms a globe of 12 or 14 inches in diameter, or more, according to the size of the intended glass-plate.

At St. Gobin it is usual to sprinkle with water the first portion of metal that is taken up on the point of the iron, in order to make it adhere better to the instrument, and thus be able to support a greater weight of glass in the subsequent immersions in the crucible.

The next object, in this stage of the process, is to convert the globe into a cylinder. This the workman effects by giving the rod to which the soft glass is attached, the motion of a pendulum. It is then heated afresh at the mouth of the furnace, and a hole is punched in the centre of that end of the cylinder which is furthest off the working rod. This is done with an iron chisel and mallet; and as the glass is previously softened by heat, there is no danger in the operation. The orifice which has been thus made is afterwards widened by an instrument kept for the purpose; and then, a pair of shears being introduced, a slit is made in the cylinder of glass extending to one half of its length.

It being necessary, however, that the cylindrical form should for the present be preserved, another workman applies a temporary rib of glass, which has been previously attached to a working rod, across that end of the cylinder which has thus been cut open. This instrument, which is called *a pontil*, is not hollow like the blowing irons, but is merely a metallic rod about 6 feet long. In France the pontil for making plate-glass has a bar of iron across the end of it, forming a T, and the rib of glass designed to be attached to the cylinder is put within a slit in the edge of the cross bar, which is designed for that purpose.

When this is done, the other rod is detached, in order to allow of that end of the cylinder being also heated, opened, and slit up with shears as before practised. The whole of the cylinder being thus divided, the pontil is detached from it, and the glass is carried to the spreading oven, where it is laid upon an elevated floor covered with a thick stratum of sand, to prevent the adhesion of the glass in its softened state. In a few minutes it is pushed on to an adjoining apartment, where it is quickly placed in a vertical position to anneal. So much care is necessary in this business, and the work is so laborious, that one man seldom makes more than 10 or 12 plates in the course of twenty-four hours.

The annealing kiln or oven having been thus filled with the plates of glass, each standing on its edge, the doors and the chimney are closed and carefully luted with clay, to prevent the possibility of any cold air entering the chamber for the space of twelve or fourteen days; after which the lutings are gradually loosened, and the glass is removed into an open part of the glass-house to attain by degrees the temperature of the surrounding atmosphere. When an hour or two has elapsed, these plates may be carried with safety to the cutting-room, and there they are trimmed round the edges with a diamond, and by other means, to prepare them for the operation of grinding. According to Pliny, the ancients used diamond powder for polishing the precious stones: but Beckmann says that the first mention of a diamond being used for writing on *glass* occurs in the sixteenth century. Francis I. of France wrote the following lines with his diamond ring upon a pane of glass, to let the duchess of Estampes know that he was jealous:

“Souvent femme varie,
Mal habil qui s’y fie.”

The ancients must however have been acquainted with our method of grinding glass, for Pliny speaks of its being turned by the wheel and engraved on like silver.—*Plin.* lib. xxxvi. § 26.

To describe all the preparations and conveniences of the grinding apartment in an English plate-glass-house, together with the varied processes of rubbing down the plates to one uniform thickness, would extend this Essay beyond its prescribed bounds: but an outline of this part of the business must be given. And with regard to the uniformity of thickness, this is necessary not only for mirrors but for the navy, where the superintendants are very circumspect in having the glass all of the defined thickness. There is an officer at each of His Majesty’s dock-yards who is provided with a gauge to measure it, and whose duty it is to reject all those squares that do not correspond to the fixed rule. The size which is most commonly used is of the thickness of 3-16ths of an inch.

In the grinding apartment the glass plates designed for mirrors or other purposes, to which plate-glass is applied, are imbedded in plaster of Paris upon a suitable table or bench, care being first taken to fix them perfectly horizontal. When the table is thus filled, other plates are attached by plaster of Paris to another plane surface; and these being suspended over the lower table, are made to traverse by a regular motion upon the surface of the former. This is effected by means of a power obtained from a steam-engine; and when the upper set of plates are thus set in motion, the attendant casts a certain quantity of sand and occasionally a little water between the two surfaces: it may therefore

easily be conceived that, by continuing this motion with repeated additions of sand and water, both surfaces will be abraded and ground down to any thickness that the operator may require. When these plates are properly ground by a succession of sands of different degrees of fineness, which are all distinguished by well-known numbers in the same way as the sportsman distinguishes his leaden shot, the plates are detached from the plaster of Paris; and having been turned so as to present the other side, they are reset in the plaster, and the same operations are repeated.

There is a process which precedes this, called *ruffing*, and other manipulations, before this business of grinding is finished. But these are so varied and multiplied that it is impossible to describe them without more prolixity than I am willing to impose upon my readers; and even then the manufactory must be visited before I could be thoroughly understood.

It may, nevertheless, be noticed, that the process of grinding reduces every hundred weight of rough plates, independently of breakage, to less than half a hundred, and that the glass which is ground off is deemed unfit for any other purpose of glass-making except that of black bottles, because it is mixed with so large a portion of common river sand, which always contains a large portion of iron. It has therefore generally been either sold at a very low rate for scouring pewter, &c. or entirely thrown away: and I remember having calculated some years ago, on the supposition of from one-half to two-thirds of the glass being abraded, that the loss of real glass at the London plate-house cannot be less than two tons per week, and the sand expended will weekly amount to at least sixteen or twenty tons.

A method has however been contrived of saving the whole of this refuse, and preserving it in a state fit for being again formed into any of the best species of glass. It consists in grinding the plates with *pure flint*, instead of the river-sand hitherto employed; therefore, when the flints have been ground so as to have no admixture of iron with them, this residuum is very fit for the purpose above mentioned, and the glass contained in it may be estimated at more value than an equal weight of pure cullet, as old broken glass is technically called. In the operation of grinding the plates, three or four tons of prepared flints are equal in effect to twenty tons of sand; the work is done in much less time; and the abraded matter, instead of being a cumbrous and useless mass, is actually an estimable residuum, admirably adapted to the purposes of the manufactory, and capable of yielding considerable profit.

In resuming the subject, I have only to add, that when the grinding is finished, the next process is that of *smoothing*, which

may indeed be considered to be a continuation of the grinding process; but this is performed by the hand, and with emery of different fineness, instead of sand.

Emery is imported in very hard solid lumps; these are ground by a powerful mill, and then sifted. The finer parts which pass through the sieve are separated into portions of different degrees of fineness, by a peculiar apparatus constructed for the purpose; but the effect is produced by a process somewhat similar to that of *elutriation*, an operation well known to chemists.

Emery, which is used for polishing metals as well as glass, is a native substance consisting of iron, alumina, and silica. It is brought from different parts of the Continent, but it is found nowhere in such abundance as in the mountains on the western coast of the Island of Naxia, the most fertile of all the islands in the Archipelago. It occurs so plentifully there, that the adjoining cape has acquired the name of Cape Emery. According to Mr. Boyle, its specific gravity is 400. From the analysis of Mr. Smithson Tennant, emery is composed of 80 parts of alumina, 3 silica, and 4 iron. The emery which is used in making scouring paper has lately been much adulterated by the admixture of old bottle glass, which is ground fine for the purpose. The common sand-paper is covered with a mixture of this ground glass and sharp sand.

The last operation is that of *polishing*. This is done with colcothar of vitriol, and is a process of only a few hours. The plates are then well washed, and squared by a diamond for sale. Such are the processes by which that kind of plate-glass is made which is produced by blowing.

Little can be known of those manufactories where large mirrors are made by *casting*, as the proprietors have always conducted their works with the utmost caution and secrecy. There are, indeed, only two establishments of the kind that I know of; the one at the Castle of St. Gobin in the forest of Fere, in the department of the Aisne, in France, as before mentioned, and the other at Ravenhead near St. Helens, in the county of Lancaster, which was established about the year 1771 or 1772, and the proprietors were incorporated by Act of Parliament.

In consequence of the secrecy which has always been observed in the conduct of this manufactory, a detail of the various manipulations for the formation of cast plate-glass could hardly be expected. But since the first edition of these Essays went to press, I have been fortunate enough to be allowed to go through the whole of these very extensive works and to examine the various operations usually carried on there, and which I was allowed to see in consequence of my having taken the precaution to procure a letter of introduction from the Committee in London,

without which I understood the resident Managers would not have been justified in admitting me.

The first thing the attendant showed me, was the operation of grinding the plates, which is a concern of great magnitude. Those plates which are designed for mirrors and other purposes where the surface must be perfectly true, are firmly imbedded, in a horizontal position, upon a wooden table or platform, and these are made to revolve one upon the other by strong mechanical power obtained from a steam engine, and by these means they grind one another; sand and water being occasionally thrown in between them, and afterwards emery and water in a way very similar to the method already described at page 372 when treating on the manufacture of plate-glass by blowing. It is observable that the plates of glass are ground in pairs, and to see so many of these of several feet diameter in one room, moving in all directions by means of machinery and with considerable velocity, astonished me not a little.

When by this method the plates are ground to one uniform thickness, they are detached from the beds of plaster and removed to the polishing room. Here the process is performed by an article called *colcothar of vitriol*, which is merely sulphate of iron first calcined to redness and then reduced to an impalpable powder. This *colcothar* is spread upon a piece of hat-felt, which is attached to a very singular kind of machine kept in constant motion by means of a power communicated by the steam engine.

The last process of polishing is performed by the hand. This is managed by women, who traverse one plate of glass over the surface of another, with great velocity and adroitness. The article which is used in this finishing process is called *tutty*. It is the white oxide of tin finely levigated. This work being completed, the plates are well washed with water, and then taken to the cutting-room, where they are squared for sale, as described at page 374.

When I had examined these processes, the guide conducted me to the Foundry, which is the great room containing the melting furnaces, the table for casting, and the annealing ovens. The building containing all these is very lofty, and by far the largest room under one roof, that has ever yet been erected in Great Britain. It is 339 feet long, and 155 feet in width.

The furnace for founding the metal and the ovens for heating the crucibles, occupy a very long range in the middle of this immense room: they stand in a longitudinal direction, and fill up about one third of the whole area.

The method of heating the furnace is very important; but as I was not at the manufactory when this operation was performed, I am unwilling to attempt to describe it. The mode adopted at the

Castle of St. Gobin is, however, too curious for a description of it to be omitted. Two persons stripped to their shirts run round the furnace without making the least stop, and with a speed equal to seven leagues in six hours: as they go along they take up two small billets of wood, of about $1\frac{1}{2}$ or 2 inches in diameter, which are cut for the purpose; these they throw into the first opening, and continuing their course do the same at the second, and at every other opening into the furnace. This circuit they continue without interruption for six hours successively, and then are relieved by others who continue the same course till the glass is completely finished. It has been thought surprising that the frequent application of two such small parcels of wood, and which are consumed in an instant, should keep the furnace to the proper degree of heat, which is such that a large bar of iron laid at one of the mouths of the furnace, becomes red-hot in less than half a minute.

At Ravenhead a row of annealing ovens stands on each side of the foundry, occupying the greatest part of the side walls of the building. These are each 16 feet wide and forty feet deep. The arrangement of these ovens is such that the plates of glass can be deposited in them immediately as they are cast, in order that they may cool as gradually as possible; and the floor of each is contrived to be on an exact level with the casting table, for the more easy removal of the plates into them. When each oven has received its destined quantity, it is shut up by an iron door, and this is secured all round with mortar to prevent any access of atmospheric air. The plate-glass remains in these ovens about a fortnight, when it is taken out, and removed to the store-room. This process of annealing is one of the most important in the whole manufactory. If it were neglected, the plates of glass would be liable to crack at every change of temperature.

The most curious part of this business, however, is the process of casting the plate-glass, which is conducted somewhat in the following manner:—When the metal has been properly prepared and has become completely refined and settled, it is laded into smaller crucibles called cisterns, which stand in the same furnace. In these vessels it remains some hours longer, or until they become of a white heat throughout, which is one of the first criterions by which the workmen judge of its fitness for being formed into plates. When the glass has acquired that exact degree of temperature which has been found by experience to be best suited for its flowing properly under the roller, the crucible containing the fluid metal is taken out of the furnace by means of a crane, and placed upon a low carriage for the convenience of moving it to the casting table, which is sometimes a considerable distance from the melting furnace.

When the crucible of hot metal is brought near the table, it is raised by a crane with a pair of gallipers a few feet from the ground, to give the workmen an opportunity of scraping the scoria from the bottom and outer sides of the crucible, which otherwise might drop off, and spoil the beauty of the plates. The pot of glass is then let down to the ground and the scum is very carefully taken off; it is then wound up again by means of the crane, and when at a sufficient height, is gently swung over the upper end of the casting table, where it is drawn on one side, and by a peculiar contrivance for throwing the crucible into an inclined position, a torrent of melted glass is suddenly poured out on the smooth iron surface beneath it. The crucible is no sooner emptied of the metal, all of an intense red-heat, than the iron roller is set in motion, and by this massive instrument the whole of the glass is spread out into one single sheet of a great size and of an uniform thickness; the thickness of the plate being determined by ribs of brass which are fixed one on each side of the casting table, and upon which the iron roller runs. The length of each plate is however in some measure determined by the quantity of metal which the crucible happens to contain; and if it should have held more than was absolutely necessary for covering the surface of the table, the extra quantity falls into a vessel of water and is employed in the next operation.

The spectacle of such a vast body of melted glass poured at once from an immense crucible on a metallic table of great magnitude, is truly grand; and the variety of colours which the plate exhibits immediately after the roller has passed over it, renders this an operation far more splendid and interesting than can possibly be described. Indeed the effect which it produces is quite inconceivable to such as have not been eye-witnesses of the manipulations in this surprising establishment.

Notwithstanding the immense scale upon which the manufactory in Lancashire is established, it appears to me, that it differs from the one in London more in the circumstance of the plates being *cast*, than in the composition of the glass itself.

From information which I have received by various channels, I apprehend the founding the metal is the same at both places; except that at Ravenhead, when the metal is made ready it is removed into other receptacles called cisterns, as already mentioned, and so contrived that they may be readily hoisted out of the furnace when every thing is in a state of preparation, and the fluid body poured from them *at once*, and as quickly as possible, upon the table, where the plate of glass is ultimately formed.

This table formerly consisted of one massive plate of copper twelve feet long and of a proportionate width, ground and polished so as to present throughout an uniformly smooth surface. It was

soon found, however, that copper is an improper metal for the purpose, it being liable to crack from the sudden transition of the heat from the torrent of melted glass poured upon it.

Several copper tables having been thus rendered useless, and a vast expense incurred in substituting one new copper table after another, the managers at length came to the determination of trying iron, and accordingly a cast-iron table of great thickness was forthwith prepared for the purpose. This immense mass of iron weighed so many tons that it was necessary to build a peculiar kind of carriage to transport it, and the other expenses of conveying it from the iron foundry to the glass works were enormous. This table, like the former ones of copper, was fixed upon a suitable frame, and this is supported by casters, for the convenience of moving the table from the mouth of one annealing oven to another.

Whether it must be attributed to the extra thickness of this metallic table or to any other cause, it may be difficult to determine; but this certainly answered the intended purpose, and appears to have sustained no injury whatever from the frequent and sudden accessions of heat to which it has been exposed. When I saw it, it had been in constant use for some years, and I was told that the proprietors thought it would last for any length of time that they could possibly require it.

It should have been remarked, that as soon as these plates have become fixed by cooling, they are thrust by main strength off the table and gradually slipped into the annealing oven immediately contiguous, and there they are treated like the smaller plates already described, excepting in one circumstance, that of their being spread out, one by one, in a horizontal position, instead of being piled on their edges, as they usually have been in those works where plate-glass is made by blowing.

The reader may conceive the advantage which must result from this arrangement, when the vast size of these plates is considered. The method of blowing answers extremely well for small plates, or for plates which do not exceed 4 feet in length and 2 feet 3 in breadth; but when larger, they have not a sufficient thickness to bear the grinding, and besides, no man could have strength sufficient to wield in his arms that quantity of glass which is required to form such immense plates as are made at Ravenhead.

The proprietors of this establishment announce by public advertisement, that they have constantly on sale at their warehouse, Blackfriars Bridge, London, glass-plates of the enormous size of six feet by twelve feet each.

That one plate should contain more than seventy square feet of glass, and yet have a surface perfectly true, is really astonishing; and when we consider that there is only one establishment

in the world that can at all compare with the works at Ravenhead, we need not hesitate in pronouncing the latter to be the most curious and interesting manufactory in the British empire.

In concluding the account of the manufacture of plate-glass, it must be noticed that the great expenses necessarily attendant upon the making of *cast* plates have obliged some of the artists in France to return to the old method of blowing; and some have been so fortunate in improving this branch of manufacture, that plates are now formed in that country, by blowing, which are 64 Flemish inches in height and 23 in breadth, (in English measure 60 inches by $21\frac{1}{2}$ inches,) a size which it had been impossible to attain before, except by the process of casting. The mass of matter necessary for this purpose, weighing more than a hundred pounds, is by the workman blown into the shape of a large bag; it is then reduced to the form of a cylinder, and, being cut up, is by stretching, rolling with a smooth iron, and other means not yet known but to those employed in the art, transformed into an even plane.—*Beckmann*, vol. iii. page 207.

Having thus briefly described the modes of making the five different species of glass, it may be proper to advert to a recent discovery in the art, and then to say a few words on the properties of glass itself.

The discovery to which I refer is that of glass incrustations, for which a patent has been obtained under the name of *Crystallo Ceramie*, by Messrs. Pellatt and Green of London. In describing this elegant and ingenious manufactory, I cannot do better than myself of Mr. Pellatt's own memoir on the subject.

The ancients were not altogether ignorant of this art; but their incrustations were very imperfect in consequence of their not being in possession of a substance for forming the device or figure to be inserted within the body of the glass, that was less fusible than the glass itself.

About forty years ago, a manufacturer in Bohemia attempted to incrust in glass small figures made with a peculiar kind of clay; but his experiments were in but few instances successful, in consequence of the clay not being adapted to adhere properly to the glass. It was, however, from the Bohemian that the idea was caught by some French manufacturers, who, after having expended a considerable sum in the attempt, at length succeeded in incrusting several medallions of Buonaparte, which were sold at an enormous price. From the extreme difficulty of making these medallions, and their almost invariably breaking, very few were finished; and I understand that the French have since then contented themselves with confining the art to the decoration of small trinkets, &c.

A patent has, however, as before mentioned, been recently taken out in this country for making these ornamental incrusta-

tions; and, if we may judge from the manner of their execution, they promise to produce a new era in the art of glass-making. By this process, ornaments of any description, heraldic crests, or portraits of any variety of colour, may be introduced into the glass, so as to become perfectly imperishable. It must be understood that the substance of which these devices are composed is *less* fusible than glass, incapable of generating air, and at the same time susceptible of contraction or expansion, as, in the course of manufacture, the glass becomes hot or cold. The ornamental figures are introduced into the body of the glass *while hot*, by which means they become actually incorporated with it.

The composition used in the patent incrustations, and which does great credit to the taste and chemical acquirements of Messrs. Pellatt and Green, is of a silvery appearance, which has a very superb effect when introduced into richly cut glass. And as miniatures and other paintings may be enamelled upon it, without the colours losing any of their brilliancy, it may be adapted to any purpose that the taste or judgement of the artist may suggest.

A most important advantage to be derived from this elegant invention, respects the preservation of dates and inscriptions. Casts of medals and coins present no equal security for perpetuating them. Had this art been known to the ancients, it would have preserved to us many interesting memorials. The inscription, when once incrustated in a solid block of crystal, like the fly in amber, will effectually resist for ages the destructive action of the atmosphere.

In reverting to the nature of glass as a chemical compound, it may be said that glass possesses several distinct and very remarkable properties, which may be enumerated in the following order. It is transparent and elastic, it possesses strong electrical powers, is ductile and fusible by heat, becomes very brittle by sudden change of temperature, and is imperishable in the fire. Dr. Merret has enumerated no less than 26 distinct properties which glass possesses, some of which were new to me and curious ¹.

It is the *ductility* of glass which qualifies it for being fashioned into such numerous shapes and employed for such a variety of purposes. Dr. Merret says, that when James Howell was at Venice he saw a complete galley, with all her masts, sails, cables, tackling, poop, forecastle, anchors, and her long-boat, all made in glass. Cardan relates that he saw a cart with two oxen in it, made with glass, and yet small enough to be covered with the wing of a fly ².

The transparency of glass is not a little surprising, when we

¹ See page 214 of his Translation of *Neri's Art of Glass*.

² *De Varietate*, lib. x. cap. 52.

consider that it is formed of substances which in themselves are perfectly opaque.

It was the *transparency* of glass which occasioned it to be so much esteemed by the ancients. The emperor Nero paid 6000 sester tia, nearly equal to 50,000*l.* sterling, for two small transparent glass cups with handles³. Glass not transparent was then in common use for various domestic utensils, also a red coloured opaque glass called *vitrum hæmatimon*, probably from *hæmatitis* the blood stone. Some of the windows in the ancient city of Pompeii were glazed with a thick sort of glass, but this was only semi-transparent. Martial, however, mentions glass in such a manner as shows it to have been common in his time for drinking vessels, and also of so transparent a texture as to admit an accurate examination of the liquor contained in them.

“Nos bibimus vitro, tu myrrha Pontice: quare?

Prodat perspicuus ne duo vina calix.”—*Epig.* iv. 86.

There must, indeed, have been a considerable number of makers of glass in ancient Rome; for we read of their having a district near the Appian gate assigned them for carrying on the manufactory. The elasticity of glass may be proved by a pane of common window-glass, which may be bent out of a straight line and yet will return again to its place without being fractured; and if glass be run out very fine like a thread, it may be folded round the finger without breaking.

If it be drawn into fine strings, it may be bent into a complete circle, and held in that position for any length of time without impairing its elasticity; for the moment the pressure is removed it recovers its form, and becomes a straight rod as before.

A few years ago a person travelled through most of the counties of England to exhibit the spinning of glass. He would spin many hundred yards of it, and as fine as silk, in a minute.

In consequence of the ready excitability of glass by friction, and its impermeability to electricity, it is the only material which is now made use of for the construction of electrical cylinders.

Unannealed glass possesses some very singular properties. Vessels of capacity made with such glass will often bear a considerable blow from without, and yet be shivered to pieces by the smallest fragment of stone, even less than a pea, if dropped in the inside; and the thicker the bottom the more easily will the effect be produced. Cups of green glass, some of them three inches thick at bottom, and which had borne the shock of a musket ball dropped from a considerable height, were shivered into fragments by letting a bit of flint weighing only two grains drop into them.

³ Pliny, lib. xxxvi. cap. 26.

It has been determined by Loysel that for the manufacture of the furnaces and crucibles an argillaceous earth which contains at least 95 per cent of quartz and alumina, and less than 5 per cent of carbonate of lime and oxides, may be employed in most of the small white glass works, where the fire is not very intense; but that the proportion of alumina and quartz ought to be 97 in each 100 pounds when it is to be employed in the great furnaces for plate and bottle glass, especially for the fabrication of the crucibles.—*Art de la Verrerie*, page 16.

The same writer states, that the materials of which these are made ought to be infusible in the degree of heat which is necessary to be employed; not susceptible of corrosion by the action of the mixtures in fusion, and capable of taking and preserving those forms which are found to be most suitable for these constructions. The best directions that have ever been given on the necessary thickness of the crucibles are to be seen in the same work. Some experiments on this subject having been made by him, he formed a valuable table for the use of the manufacturers of glass, to show the respective thickness of the crucibles of various diameters, all which are estimated according to the different degrees of the tenacity of the materials.

In addition to the various remarks which I have made on the construction of the crucibles, I am desirous of annexing the following important observations.

“Pottery,” says Loysel, “is one of the most difficult and delicate parts of the art of glass-making, and merits the strictest attention. If the pottery is perfect, the artist has the power to manage the action of the heat, to vary at pleasure the vitrifiable compositions, to regulate the melting, the refining, and the whole works. He knows beforehand the products of his fabrication, and directs it to his greatest advantage. If on the contrary the pottery is bad, all is confusion. The first cost of the materials, their preparation, and the expense of the workmanship, turn to entire loss, and the ruin of the proprietor is inevitable. No expense therefore, or care, ought to be spared to procure good pottery.”

The English glass-makers labour under an inconvenience which is not felt in France and some other countries on the Continent of Europe. In consequence of their heating their furnaces with pit coal, they are under the necessity of making their best flint glass in *covered* pots; and as the heat is much lower in the interior of a covered crucible than in an open one, we are obliged to make our glass of more fusible materials; and consequently, by using a large portion of lead, and less silica, we produce a softer glass than is prepared by those who have an abundance of wood fuel.

It appears to me that there can be no certainty in the process of annealing without the use of a pyrometer; and as the glass manufacturers have frequently to make experiments on clays, have not such persons excellent opportunities of contriving such an instrument as would suit not only this purpose, but serve for the large furnace also? Glass made with alkali and silica only, is more difficult to anneal with certainty than such as contains lime and lead in its composition.

Soda is preferable for making glass, inasmuch as it requires more silica for its saturation than potash; and it will not be denied that the greater the quantity of the siliceous earth which can be made to enter into the composition of glass, the harder will that glass be, and the less liable to be injured by abrasion.

In making glass, "if the combination be such that in 1000 parts there remain only 200 or even only 150 parts of alkali, the glass is hard, clear, brilliant and transparent, and approaches the beauty of rock crystal. The excellence of flint glass is in direct ratio to the quantity of silica, and in inverse ratio of the quantity of alkali."—*Loysel*, page 113.

Moreover, soda, as was before mentioned, will make a more fluid metal, and thus the manufacturer will at all times be more likely to separate all the sandiver, for this rises with more difficulty to the surface when the glass is made with potash; and it is well known that, wherever any of the sandiver or glass-gall remains in the finished glass, it will occasion striæ, clouds or bubbles, either of which very much lessen its value.

When plate-glass is to be made with potash, it is generally thought requisite to add some borax to the composition to render the metal more fluid, otherwise it is apt to stiffen before the plates can be completely formed. This is another objection to the use of potash for this particular species of glass. On these accounts it is of importance always to use soda for plate-glass, and also for such flint glass as is intended to be employed for particular purposes; especially for such articles as are required to sustain much wear.

It is however generally imagined that potash will make the *whitest* glass, though such glass is more apt to be *seedy*, as the workmen call it, that is, to be full of very minute specks, which greatly impair its beauty, and diminish its value.

A friend of mine in the glass trade has however assured me that he never could make flint glass, even with the purest soda, so perfectly white as he could with pearl-ash, though he repeated the experiment many times and with every precaution.

Since then I have had an opportunity of examining several specimens of flint glass made with soda and others with potash; and I am now inclined to think that very brilliant flint glass, per-

fectly pellucid and colourless, cannot be made with soda, but that potash is absolutely necessary for this particular species of glass. The potash ought however to undergo a complete purification from all neutral salts, before it be employed for wine glasses or for any kind of ornamental flint glass.

It may in some cases be safer to use soda, because, where too much alkali has been employed, such glass will be less likely to be injured by exposure to the atmosphere in damp situations than glass made with the vegetable alkali, which is always liable to deliquescence. I am, perhaps, justified in this observation by a remark of Dr. Merret, in his examination of Neri's Art of Glass. "In old windows of French glass, in that part," says he, "which lies towards the air, you may discern pieces of salt; and in the finest glass, where there is a great proportion of salt to the sand, you shall find that such glasses standing long in subterraneous places, will fall to pieces, the union of the salt and sand decaying." Fourcroy also says, that glass made with soda is best for holding the mineral acids, as such glass is decomposed with more difficulty by acids than such as is made with potash.

Borrichius relates, that he saw several glass lacrymatories dug up at Rome which had lain in the ground several hundred years, and that the glass was split into an infinite number of laminæ like the Muscovy talc, and yet these laminæ were smooth and transparent. This effect was probably occasioned by the use of potash in the glass, and the employment of too large a quantity of that alkali.

I would not, however, in these remarks be misunderstood; for it is impossible to be sure of having perfect glass unless an extra quantity of alkali be employed: but then care must be taken to prolong the process till the whole of this excess be separated from the mass and volatilized.

Shaw has a remark to the same purpose. "In order," says he, "to give our glass the desired degree of hardness, it is proper to continue it long in the fire, which is constantly found to add strength and hardness to glass. Common glass, by being constantly kept in a strong fusion for a month or six weeks, has become of a stony hardness, approaching to the native hardness of the flint or sand employed in its preparation."—*Chem. Lect.* p. 427.

I have also to recommend that frequent attention be paid to the price of salt-petre, because I am persuaded that whenever this article is at a low rate it must be advisable to employ it for flint and crown glass in preference to American pearl-ash; inasmuch as it contains a large portion of alkali, and is free from those neutral salts with which pot- and pearl-ash of every kind are contaminated. Where metallic oxides have been employed to colour glass, either for windows or for the imitation of the precious

stones, nitre is found to be of great use, as it tends to preserve the metallic oxides in a high state of oxidizement, and thus imparts great vivacity to the colours. Nitre is composed of 47 per cent. of pure potash and 53 per cent. of dry nitric acid.

Agricola knew the value of nitre in making glass. "The first place," says he, "must be given to saltpetre, the second to fossil salt¹."

It has been said that borax (subborate of soda) will make a harder glass than either of the pure alkalies. Borax consists, according to Bergman, of 34 parts of boracic acid, 17 parts of soda, and 49 parts of water.

This saline substance was known to the ancient Romans. We read of the Circus in the time of one of the early Cæsars being covered with vermilion and *borax*². Whether borax or *tincal* could be procured in quantity cheap enough to be employed in glass-making, I know not. Dr. Shaw relates, that with four ounces of borax and one ounce of fine white sand he formed a pure glass, which was so hard that it cut common glass like the diamond.—*Chem. Lect.* p. 426.

It would be advantageous, I conceive, if some method could be devised of frequently stirring the fluid metal in the crucibles, so as always to ensure the production of glass that shall have a perfectly homogeneous character. In a former part of this Essay I have mentioned the circumstance of veins or striæ appearing in flint glass. These might generally be prevented by the adoption of the expedient which is now suggested, because they arise from the want of due uniformity in the mixture of the compound mass.

Loysel has shown that the various specific gravities of the different compounds which are formed, such as those with alkali and silica; alkali and clay; and, lastly, alkali with the metallic oxides; are fully sufficient to account for the production of these imperfections, and that nothing but a more uniform mixture of the different materials, together with complete fusion, can prevent their appearance.

"Glass made at a great degree of heat will always be lighter than that made at a lower temperature. The first contains more silica and less alkali, whereas the specific gravity of glass augments according to the greater quantity of alkali that is combined with it." "Glass made to contain 80 silica and 20 alkali will have a specific gravity of 2.36, whereas that which is composed of 54 silica and 46 alkali will be 2.54." Might it not be advisable for the proprietor of every glass-house to take the specific gravity of each pot of metal when finished? as this would always be a

¹ Agricola *De Re Metallica*.

² Suetonius in *Vita Caligulae*, § 18.

guide to show whether the workmen had observed due care in keeping the furnace at a proper degree of temperature.

In treating this subject, Loysel remarks, that "glass made with silica and the fixed alkalies has a specific gravity of 2.3 to 2.4; that formed with alkali and clay 2.5; that with alkali and chalk 2.7 to 2.8; the oxide of manganese if vitrified by itself 3.2 or 3.3; while the glass made with oxide of lead will be 7.2 to 7.3 of specific gravity." When these different kinds of vitrified products occur in the same crucible, and a complete mixture of them has not been effected, it is not surprising, he observes, that the glass should be imperfect.

The art of making glass seems to depend upon the successful or perfect union of two or more metallic oxides which have an affinity for each other. On this principle it is that potash, an oxide of potassium, and silica, the oxide of silicium, are fused together and form glass. One part of silica and two parts of borate of soda unite and form a transparent colourless glass. One part of silica and three of oxide of lead form good green glass, and it is well known at all the iron furnaces that silica, when united to the oxide of iron, produces a perfect black glass of extreme hardness and durability.

The principal Acts of Parliament now in force respecting the manufacture and sale of glass, are as follow:—viz. 19th Geo. II. chap. 12; 17th Geo. III. chap. 39; 24th Geo. III. chap. 41; 35th Geo. III. chap. 114; 38th Geo. III. chap. 33; 38th Geo. III. chap. 89; 43d Geo. III. chap. 69; and the 53d Geo. III.

ESSAY XII.

ON BLEACHING.

FLAX and hemp were employed in the fabrication of cloth many ages ago, and in those early times such cloth was highly esteemed; it must therefore long before that period have been discovered that these fabrics were improved in colour by exposure to the action of the atmosphere. The effect of hot water in whitening brown linen would also soon arrest the attention of mankind; and when it became a practice with the early inhabitants of Asia to employ certain earths and alkaline plants in the operations of washing and scouring their garments, the whitening, as well as the deterative properties of these vegetables, could not fail to be observed, and, by degrees, would naturally occasion the introduction of regular processes for bleaching; and that this art was practised very early, is, I think, evident from the great progress which it had made in the beginning of the Christian æra.

That the ancients had learnt some method of rendering their linen extremely white, may be supposed from many remarks which are interspersed among their writings.

There is a passage of Pliny, an author whom I have often quoted, and who published his *Natural History* in the first century, which to me appears perfectly conclusive.

“Of late days,” says he, “there were seen in the amphitheatres of the Emperor Nero, fine curtains of blue azure colour like the sky, and the very floor of the ground under men’s feet was coloured red. But for all these paintings and rich dyes, yet, when all is done, the white linen held the pre-eminence still, and was highly esteemed above all colours¹.”

Pliny has likewise informed us, that the Gauls and Britons of his time were acquainted with a method of bleaching linen cloth, and he thus describes their process. “After the flax is spun into yarn, it must,” says he, “be bleached and whitened by being pounded several times in a stone mortar with water: and lastly, when it is woven into cloth, it must be beaten again upon a smooth stone with broad-headed cudgels, and the more frequently it is beaten it will be the whiter and softer².” The same author tells us that they sometimes put the roots of wild poppies into the

¹ Holland’s *Pliny*, vol. ii. p. 5.

² Plin. *Hist. Nat.* lib. xix. cap. 1. § 9.

water, to make it more efficacious in bleaching linen¹. “There is a kind of poppy (says he) much sought after for bleaching linen cloth; for, being scoured therewith, it is wonderful how white and pure they will look. And yet people are grown to this disorder and vain enormity, that they have essayed to stain and dye their linen into other colours, as well as their woollen cloths².”

We learn from Theophrastus, who was the son of a fuller in the Isle of Lesbos, and who wrote 300 years before Christ, that lime was then employed in bleaching. He relates, that a ship partly loaded with linen, and partly with lime for bleaching it, was destroyed by the accidental access of water to the lime.

Although it should be proved that the bleaching of linen is a process of very great antiquity, it must not, however, be supposed that any people were acquainted with it in the earliest stages of their society, or before they had acquired some degree of civilization.

The vestments of the early inhabitants of the world discovered neither art nor industry. They made use of such as nature presented, and needed the least preparation. Some nations covered themselves with the bark of trees, others with leaves, or bulrushes, rudely interwoven³. The *skins* of animals were also universally used as garments, worn without preparation, and in the same state as they came from the bodies of the animals⁴.

In process of time recourse was had to the *wool* of animals, and this led to the further discovery of the art of uniting the separate parts into one continued thread, by means of the spindle; and this would consequently lead to the next step, the invention of weaving, which, according to Democritus, who flourished four hundred years before Christ, arose from the art of the spider, who guides and manages the threads by the weight of her own body. That the invention of weaving was long prior to the time of Democritus, appears from the sacred writings.

After the art of weaving had been invented, it was probably not long before flax, hemp, and cotton, were employed in the fabrication of garments, especially as the President Goguet has abundantly proved that vestments of cotton were in use in the Patriarchal ages⁵; and there can be no doubt that in the time of Christ several nations had acquired great proficiency in the manufacture of linen cloth.

Pliny describes, as growing in the higher parts of Egypt, the cotton shrub of which cloth was made, and “of which,” he says,

¹ Plin. *Hist. Nat.* lib. xx. cap. 19. § 2.

² Holland's *Pliny*, vol. ii. p. 5.

³ Strabo, lib. xi. p. 781. Senec. *Epist.* xc. p. 406.

⁴ Lucretius, lib. vi. ver. 1011. Pausanias, lib. xx. c. 38.

⁵ Goguet, book ii. p. 127.

“the Egyptian priests were wont to have *surplesses*, in which they took a singular delight⁶.” He also tells us⁷ that vestments of cotton were worn by the ancient Egyptians; and more than a thousand years before the commencement of the Christian æra, Moses speaks of robes of linen, and commands his people “not to wear a garment of divers sorts, as of woollen and linen together⁸.” The dress of the ancient Babylonians consisted of a tunic of lawn, which they wore next to their skin. It descended, in the Eastern mode, to their feet⁹. The Athenians wore long robes of fine linen dyed purple¹⁰.

It is not likely that the materials of which we have been speaking were long employed in the manufacture of garments, before some method was adopted of improving their colour by artificial means, as has been already hinted. This will appear still more probable, when we consider that some of the early inhabitants of the world had several methods which in themselves tended very much to whiten linen and cotton cloth.

The evidence of Pliny is alone sufficient to prove the truth of this assertion. “The Faventine cloth,” says he, “is always far whiter than the Allian, which is ordinarily brown when it is new woven, and before it be bleached. The Retovine linen is exceeding fine; the thread itself is more even (if evener may be) than that which the spider spinneth.” “I myself have seen so fine and small a thread of Cumes flax, that a whole net knit thereof would pass through the ring of a man’s finger. I have also known one man carry so many of them (easily) as would go round and compass a whole forest¹¹.”

Homer describes Nausicaa and her companions washing their clothes by treading them with their feet¹²; and according to Pliny, the ancient Greeks and Romans were acquainted with the deter-sive properties of several kinds of earth, as well as of several plants, which they employed in scouring linen¹³.

Having hazarded these few introductory remarks, it may perhaps be convenient to divide the subject itself into two parts, consisting of the European methods of bleaching before the discovery of chlorine gas, and of the practices which have been adopted since that period. I shall then conclude this Essay with a brief account of some of the present most important desiderata in bleaching, accompanied with such hints or proposals which, on a chemical review of the subject, may suggest themselves as proper to be submitted to the consideration of practical men.

⁶ Holland’s *Pliny*, vol. ii. p. 3.

⁷ Pliny, lib. xix. § 2.

⁸ *Deuteron*. xxii. 11.

⁹ Goguet, vol. iii. p. 187. Herodot. lib. i. n. 195.

¹⁰ Thucyd. lib. i. p. 6. n. 6.

¹¹ Holland’s *Pliny*, book xix. chap. 1.

¹² *Odyss*. lib. vi. ver. 92.

¹³ Pliny, lib. xxxv. § 57; lib. xxvii. § 88.

Half a century ago the linens of Holland ere the most esteemed of any in Europe, and this arose in a great measure from the superior skill of the Dutch in bleaching. An account of the process in the great work at Haarlem, and which I copy from a scarce book, printed in the year 1754, entitled "*Select Essays on Commerce, &c.*," will therefore, I trust, not be uninteresting to the modern bleacher.

"The whitening grounds of Haarlem," says the author, "are situated about a league from the city gates, and the most considerable of all is in the neighbourhood of the village Bloemendaal. The cause of the wonderful whiteness in the Dutch cloths is ascribed to the lye-ashes of Muscovy, and to the water of their downs; which is nothing else than sea-water, which, filtrating through the downs and mountains of sand, bursts out perfectly sweet and clear.

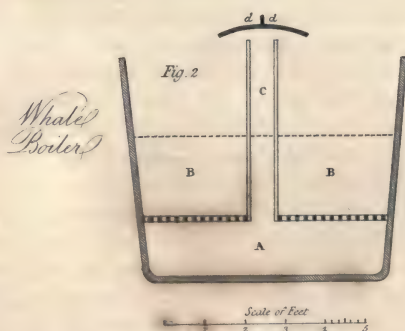
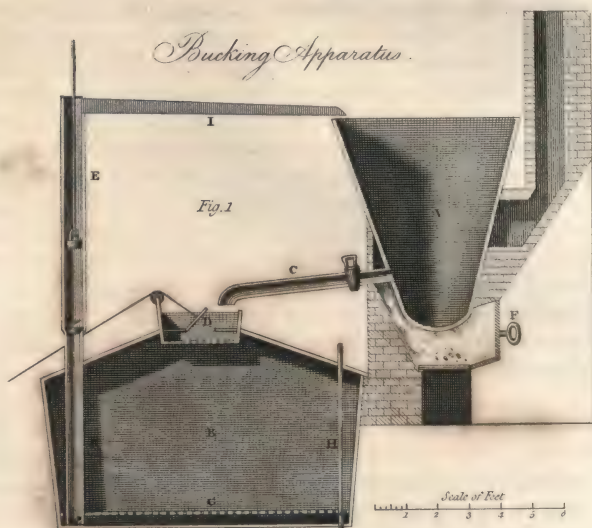
"When a piece of linen is to be bleached, it is in the first place steeped in a lixivium or lye, where other cloth hath been trod; afterwards it is trod in a new lye of lye-ashes, poured upon it boiling hot. This is boiled in large copper caldrons, and is never poured upon the cloth till it is as clear as wine. The linen is left eight days in this lye, after which it is washed and pressed in this manner.

"They empty some buckets of butter-milk into wooden vessels fixed in the ground, then they throw in a piece of linen, which three men tread with their feet as much as possible. Afterwards they pour in more butter-milk, and then another piece of cloth, proceeding thus alternately till the vessels are nearly filled, when they lay planks over the linen, upon which they raise a large round piece of wood, or great stake, touching the lower side of a beam, between which and the stake they drive wedges, to press the cloth. Six or seven days after, they take the cloth out of these vessels; and if it be not white enough, they steep it as we have described above. Afterwards it is washed, and spread out upon the ground to bleach. It must be remarked that, after every dipping, the cloth is washed first with black soap, then with clear water, and, after each of these operations, is wrung by means of a machine that turns with a wheel."

It will not much interrupt this narrative to remark, that at this period, no one attempted to explain the operation of the atmosphere in bleaching. Many years afterwards, Mons. Berthollet, in order to be able to account for the effect of crofting linen and cotton goods, examined the dew which falls from the atmosphere, and also that which transpires from the grass, and found both to contain a sufficient portion of oxygen to destroy the colour of turnsol paper.—*Annales de Chimie*, tom. ii. p. 158.

"The whitening grounds are cut with canals in sundry places,





C. B. Hoag delin.

Jas. Davis sculp.

- A. Boiler for heating the lye... E. Pump for raising the liquor...
 B. Vessel for the calicoes... F. Furnace for heating the lye
 C. Pipe to convey hot lye... G. The false bottom...
 D. Box for spreading the lye... H. Plug for emptying vessel...

that there may be no trouble of fetching water from a distance. The cloth is watered with long narrow shovels made in the shape of a scythe. The water of these canals comes from the downs, and it is that which contributes most to the lustre of the Dutch cloth. To prevent the water from becoming thick and muddy, they are extremely careful in cleaning their canals. The washing tubs are built in with bricks, with two trap doors, or sluices, for admitting or excluding the water, according as it is necessary.

It would occupy too much room in these pages to describe separately each of the processes that were formerly adopted in these kingdoms for bleaching; but, as that of flax yarn was one of the most important, I have thought it worth while to relate how this was conducted, under an idea that such a detail will prove interesting to the young bleacher, who has yet had no opportunity of witnessing any operation but that which is effected by chlorine gas, or the salts which are formed by its means.

A pound of linen yarn cannot be bleached at less than four times the expense of bleaching a pound of cotton yarn. The reason is, that the quantity of colouring and resinous matter to be abstracted from the one is much greater than from the other. The thread made with flax will lose 27 per cent. of its original weight before it becomes perfectly bleached; whereas cotton yarn will lose only $4\frac{1}{2}$ or 5 per cent. by a similar operation.—The following was the process usually adopted for bleaching flaxen yarn.

The first operation, that of *steeping*, is extremely simple. It consists merely in immersing the brown yarn in hot water, or otherwise allowing it to macerate cold in waste alkaline lyes. When pure water only was used, the goods were generally kept in it for three or four days, whereas with cold alkaline waste lyes forty-eight hours were usually deemed sufficient.

The intention of steeping was to occasion a kind of vegetable fermentation, which loosened the saliva employed in spinning the yarn, and so far separated the other impurities attached to it, that the whole were afterwards easily removed by washing in river or spring water, and which, in large concerns, was usually performed by machinery.

The next operation was that of boiling in an alkaline lye, or *bucking*, after which the skeins were exposed on the grass for two or three weeks, and then boiled or bucked a second time, again well washed, and then crofted as before. *Bucking* is a technical term for boiling, or steeping, in hot alkaline lyes, in an apparatus which is so contrived that the lye flows alternately over the goods and into a heated copper¹. From this a pump, which is

¹ A drawing of this apparatus will be seen in the Plate of the Bucking Apparatus.

usually worked by steam, throws it again on the goods, through which it percolates till it reaches the bottom of the vessel, when, by the removal of a plug, it is run off again into the boiler, where it becomes again heated, and from whence it is pumped up as before, and the process goes on uninterruptedly for many hours. According to Dr. Home, clear sunshine, with a very little wind, is the best weather for bleaching. Crofting is a technical phrase for the act of exposing linen or cotton goods on the grass. These alternate operations of bucking, washing, and crofting, were generally repeated four or five times, each time lessening the strength of the alkaline lixivium in which the bucking was performed.

The next process was that of *souring*, which consisted in soaking the yarn in milk which had become acidulous by age, and which was usually employed for the first time immediately after the fourth or the fifth repetition of the bucking or the boiling operation. In this liquor, which was technically called the *first sour*, the goods generally lay for two or three weeks, or until such time as the scum began to crack and subside, when they were usually taken out and submitted to a repetition of the several operations already described.

Thus, whenever the goods had been once soured, the operations of bucking, washing, souring, and crofting, were repeated in regular rotation, until the yarn came to a good colour, and was esteemed perfectly clean. And it should be remarked, that these alternate applications of the alkali and the acid, in this mode of bleaching, were absolutely necessary to give the oxygen of the atmosphere an opportunity of acting upon the colouring matter, and preparing it for the next operation. In these operations the alkali probably carbonizes the colouring matter, or puts it in a suitable state for the oxygen to convert it into carbonic acid, or into a gaseous substance, easily carried away by the wind, viz. carbonic acid gas. For if any portion of the alkali was left in the goods when they were laid on the meadow, it would not only prevent the whitening process from going on properly, but would impair the strength of the article, and in like manner, though in a less degree, the goods would be injured by the remaining acid; but by the contrivance of using the acid and the alkali alternately, each of them becomes neutralized, the resulting salt has no injurious action on the fabric, and yet it is in a state for being easily removed by washing in pure water. In these latter operations a portion of soap was always employed, it having been found that this had the effect of making the goods handle better, and also of cleansing them more effectually.

This method of bleaching was extremely tedious, so much so, that if the first operation was begun in the month of March, the goods were seldom finished before September; and such as were laid on the grass for the first time at Midsummer, were only

about half bleached that year, and were laid by to be finished in the spring of the following year. The probable reason why the proprietors of bleaching grounds took no measures to prevent this interruption of the process was, because they had found by experience that the atmosphere during the months of March, April, and May, acted more efficaciously in whitening the goods.

About the middle of the last century, these tedious operations were much shortened, by the employment of sulphuric acid, instead of sour milk; an improvement first suggested by Dr. Home, in consequence of the new and important process, adopted about that time by Dr. Roebuck, for manufacturing sulphuric acid, which reduced that acid to one-fourth of its original price.

The public was, however, much alarmed by the introduction of this acid, on account of its corrosive nature, till Dr. Home published a volume on bleaching, in which he stated how much the sulphuric acid is always diluted for this purpose, and that "he had kept linen in a strong sour of oil of vitriol for many months, and that the cloth was as strong after it was taken out as when it was put in."

No sooner was this new agent employed in bleaching, than it was discovered that one souring with sulphuric acid might be finished in 12, 18, or, at most, in 24 hours; whereas every souring by the milk process required from two to six weeks, according to the state of the weather and other adventitious circumstances. Besides, sours of this description hasten very fast to corruption. Indeed, as the milk is generally kept very long, it is often corrupted before it is used, and then, without acting as an acid, it has all the bad effects of putrefaction in injuring the fibre and weakening the cloth; whereas the sours made with sulphuric acid are not liable to putrefaction.

The mere introduction of sulphuric acid occasioned such an improvement in the art of bleaching, that the whole process might then have been easily finished in four months, though it had formerly required seven or eight months for its completion.

The most important discovery, however, in this business is that of chlorine, and its application in whitening goods made either of linen or cotton. The introduction of this article forms absolutely a new æra in the history of this art; for it not only expedites the process surprisingly, but has become the means of reducing the practice of bleaching to a perfect science.

For this most important discovery we are indebted to Scheele, who in the year 1774 first obtained chlorine by art, and afterwards ascertained its power in destroying vegetable colours; although it appears that at first he investigated its nature more as a matter of curiosity than of use.

Several years seem to have elapsed before any one thought of applying the peculiar properties of this singular gas to any important purpose; and I presume it was not suspected that this powerful agent might be employed in any considerable process of bleaching linen or cotton until about the year 1784.

The first person who made experiments upon this gas, with a view to its successful application in the arts, was M. Berthollet, the French chemist, who in the *Journal de Physique* for June 1785, and again in the number for August 1786, explained the nature of its action on vegetable colours, and suggested how it might be employed with advantage in any of the existing establishments.

In the year 1787, the Academy of Montpellier transmitted to Chaptal several observations on chlorine, in order to their being printed in the National Memoirs for that year; and a report on the subject of this communication was immediately presented to the Royal Academy of Sciences. This report, which contains many very interesting particulars, was afterwards given to the world in the *Annales de Chimie*, tome i. p. 69.

In the early part of the year 1787, Mr. Copland, Professor of Natural Philosophy in Marischal College, Aberdeen, was accompanying the present Duke of Gordon in his travels on the Continent, and they passed some weeks at Geneva, with Professor de Saussure, under whose direction His Grace had studied in the early part of his life; and he showed these travellers the experiment, which they had already heard of, but had never before seen, of discharging vegetable colours by means of chlorine gas.

Impressed with the idea of the importance of this discovery to our manufactures, Professor Copland, on his return home, communicated all the circumstances and displayed the properties of the new gas to Messrs. Milnes, particular friends of mine, eminent manufacturers in that neighbourhood, who immediately entered upon a course of experiments for the preparation of chlorine, with a Woolfe's apparatus, and obtained a very satisfactory result.

This was about the end of July 1787, being, I believe, the first actual application of chlorine to the purpose of bleaching either linen or cotton goods for sale in Great Britain; and from that time these gentlemen continued to apply this mode of bleaching in their manufactory, especially for finishing such orders as were limited in point of time. But, in applying this discovery to actual practice on a large scale, they very soon perceived that the circumstance of the gas being prepared in an apparatus of glass, would be a serious obstacle to its general adoption; and therefore, when they came to extend its application to larger quantities, they made use of vessels of white wood instead of glass.

At the time of which I have been speaking, M. Berthollet had been engaged for twelve months in investigating the nature of

chlorine gas, for the purpose of ascertaining the best and most economical methods of applying it in whitening cotton and linen cloth. Just then, Mr. James Watt, of the Soho, Birmingham, happening to be at Paris, M. Berthollet invited that eminent man to witness his experiments; and it appears that he communicated to him, without reserve, the full amount of the discoveries which he had made in the new process of bleaching.

On the return of Mr. Watt to Great Britain, he appears to have lost no time in communicating the whole of the information he had obtained, to his relative Mr. MacGregor, a large bleacher at Glasgow; for, in his subsequent correspondence with M. Berthollet, he informed him, that he had applied his discovery to real practice, and in his first attempt had bleached five hundred pieces of cloth by the new method. He adds that Mr. MacGregor was so highly satisfied with the result, that he had determined to continue the process.

When these circumstances are all considered, it may be difficult, at this distance of time, to determine whether chlorine gas was first employed in the bleach-field of Mr. MacGregor at Glasgow, or in the works belonging to Messrs. Milnes at Aberdeen; or, in other words, whether Professor Copland or Mr. Watt is entitled to the credit of having first introduced gas bleaching into some of the then existing establishments of Scotland. Be this, however, as it may, it is pretty clear that both these gentlemen were zealously engaged in the same undertaking about the same period, and that the process was fully established at Aberdeen and at Glasgow long before it was employed in any other part of Great Britain.

But to pursue the account: In the year 1788, the attention of several persons at Manchester, particularly that of Mr. Thomas Henry, was directed to the subject, and an experimental examination of the nature of the new bleaching agent was entered upon by several individuals who had usually been engaged in different pursuits, but who were all stimulated by the hope of obtaining either private or public advantage from the result of their investigations. Just now, however, an unexpected circumstance occurred, which was thought likely to be very injurious to the town and trade of Manchester, and this had the effect of uniting the efforts of those persons in that town and neighbourhood, who had been endeavouring to acquire a knowledge of the new process of bleaching by means of chlorine gas. M^{rs}. M. Bourbollon de Bonnueil and Co., French Chemists, had applied to the English Parliament for an exclusive right to the invention of a liquid for whitening linen and cotton in a shorter time than by the old method; and this so alarmed the printers and bleachers of Manchester, that a meeting of the manufacturers and merchants of the

town was called by public advertisement, for the express purpose of considering the plans and the petition of the said foreigners.

At this meeting half a piece of calico was produced which had been bleached immediately before, by Messrs. Cooper, Baker and Taylor, by the new method; and at the same meeting Mr. Thomas Henry produced, not indeed half a piece, but half a yard of calico, which he had just bleached by chlorine gas. What was wanting, however, in quantity, was made up by the quality of the work; and the smaller specimen was declared to be superior in whiteness to the larger one.

The result of the public meeting was, that in consequence of the specimens of bleached calico which had been produced, and of the facts stated by Mr. Henry, and Mr. Thomas Cooper, who was also a man eminent for scientific attainments, and of a letter from Mr. Watt to Mr. Henry, which was read to the meeting, stating that he had at that very time 1500 yards of linen bleaching by the new process under his direction, the members for the county were instructed to oppose the petition above mentioned, when presented to Parliament. The consequence of this was, that the petition was refused; and afterwards, when the same people made application for a patent to secure to themselves the sole right of selling a bleaching liquid, Mr. Henry drew up a Memorial, which was presented to the attorney-general against the claim of the petitioners, and which contributed in a considerable degree to their want of success. This document is dated July 2, 1788, and contains an account of the processes then actually practised by Mr. Henry, and comprehends every thing at this day known respecting the use of chlorine gas in bleaching, with the exception of the application of lime to the condensation of the gas. This document, which is still preserved, places beyond all controversy Mr. Henry's right to rank among the first improvers of the process of bleaching.

Soon after the Manchester meeting of which I have spoken, Mr. Charles Taylor, a calico-printer of Manchester, in conjunction with Mr. Thomas Cooper, also of Manchester, bleached a whole piece of cotton by the new process, and printed and calendered it fit for the market in less than three days. The success of this experiment was so decisive and unexceptionable, that Mr. Cooper and some other neighbouring gentlemen were induced to establish at Raikes, near Bolton, in Lancashire, a bleaching concern of very considerable magnitude, to be dependent entirely upon the agency of chlorine gas.

In the year 1789, which was one year after those favourable specimens of the facilities of the new method of bleaching had been exhibited in Manchester, as mentioned above, M. Berthollet brought the subject again before the public in a masterly

memoir, entitled "*Du Blanchiment des Toiles et des Fils par l'Acide muriatique oxigéné, et de quelques autres Propriétés de cette Liqueur relatives aux Arts.*" His directions are, to use

6 ounces of pulverized oxide of manganese,
1 lb. of sea salt,
12 ounces of sulphuric acid, and
12 ounces of water.

A folio plate, accurately engraved, accompanies the volume, with letters of reference, and such an ample description that nothing can be mistaken.

This memoir contains so many interesting particulars respecting the progress of the new art, that it would be impossible for me to do justice to the subject which I have undertaken to elucidate, without repeating some of the circumstances related by this very acute writer.

At first he was perplexed by the discovery that the cloth was injured by the process; but in subsequent experiments he found that, when the liquor was considerably diluted, he was enabled to bleach without impairing the strength of the fabric. Another difficulty which he had, arose from the cloth sometimes becoming yellow after an interval of a few weeks; and this occasioned him much trouble. However, when he began to try the alternate action of the chlorine gas and alkaline lyes, he discovered that he was able to procure a perfect and permanent white. I doubt not that Berthollet speaks here of his success in bleaching cotton, because the process which he describes always leaves a yellowness on linen goods, which can only be removed by a few days exposure on the grass.

In the mean time, while M. Berthollet was engaged in these experiments, a M. Bonjour, who had been an assistant to Berthollet in his first attempts, connected himself with a M. Constant, a cloth finisher at Valenciennes, for the purpose of forming a bleaching establishment at that town; but, owing to the violent opposition of the neighbouring bleachers, they were unable to procure ground for the purpose on any reasonable terms.

In this difficulty, a patriotic French nobleman, the Count de Bellaing, who favoured the enterprise, and was made acquainted with the extent of the opposition, gave them possession of a piece of land at some distance from the town, which had all the necessary conveniencies for the business. Here a large establishment was formed in the course of the year 1788; but notwithstanding the support which the proprietors had thus received, the opposition of the old bleachers, and the inveterate prejudices of the neighbourhood, were so great, that Mons. Bonjour was under the necessity of addressing the National Bureau of Com-

merce on the occasion. The chief prejudice arose from the circumstance of the new proprietors intending to substitute *chemical* bleaching for the old process of ashing and crofting.

Soon after this period, some manufacturers at Javelle, near Paris, announced in several journals, that they had discovered a particular liquor, which they called the *Lye of Javelle*, having the property of bleaching cloth by a few hours immersion. This composition, which was immediately analysed by Berthollet, was found to be nothing more than a solution of the chloride of potash; and, on his attempting to prepare the solution, he immediately perceived that the addition of the potash to the water caused it to imbibe the gas sooner, and that it likewise formed a more concentrated liquor. This was similar to the liquid which is now sold in London in small bottles, under the name of bleaching liquid, for the use of private families. A convenient article for this purpose may be prepared by receiving the gas which arises from the distillation of 3 pounds of common salt and 1 pound of manganese, into a receiver containing 1 pound of best American pearl-ash dissolved in 4 pounds of water. Two pounds of sulphuric acid previously diluted with 4 pounds of water, will be sufficient for extricating the gases from the materials above mentioned.

At the time when Berthollet published the memoir from which I have taken some of the foregoing particulars, few persons in England were acquainted with any mode of bleaching by means of chlorine, except when in the state of gas; and in this way many attempts were made, in various places, by some of the best informed and most practical men in their respective districts.

At Nottingham, some considerable manufacturers succeeded tolerably well in bleaching small parcels of linen yarn, linen, and cotton hose, and other small goods, which they effected in the following manner: The articles having been suspended within large wooden boxes, each of which had a close bottom capable of holding water, the gas was conveyed into these receptacles; and, to prevent any injury by the immediate application of the gas, the goods were, by means of a frame and pulley, let down occasionally, and indeed frequently, into the water beneath. But by this method there was great difficulty in exposing all the surfaces of the goods equally, without which no perfect bleaching can ever be effected.

This practice was continued, however, with considerable advantage, though not without its inconveniencies, until the manufacturers of Javelle, before mentioned, having been disappointed in their commercial prospects at home, came over to England, and settled at Liverpool, for the purpose of manufacturing the

solution of chloride of potash, which they proposed to sell to the English bleachers in bottles, and which they still denominated the *Liquor de Javelle*.

These men, although they had been unable to introduce their article in France, so that it might have been consumed in sufficient quantities to answer their purpose, were so sanguine respecting the sale of it in England, that they applied to the British Parliament for an exclusive right to the invention, for the term of 28 years, as before mentioned. Fortunately, however, one of the gentlemen who first applied chlorine to the purposes of bleaching in this country, as mentioned at page 393, happening to be in the gallery of the House of Commons at the time the application was made in behalf of these foreigners, he took immediate measures to inform the principal members that this was not a new process; that he himself had long ago prepared an article equally efficacious, and that he would be ready to substantiate the truth of his statement when required. This representation, together with the petition from the town of Manchester, had the desired effect—the purpose of these Frenchmen was defeated, and the Act which they had petitioned for, was not obtained.

Notwithstanding this disappointment, these gentlemen continued to carry on their work at Liverpool for a considerable time: but, from the article being bulky, and from its constant loss of strength by the action of light, or by exposure to the air, the obstacles to its consumption continued to augment, until in the end they were obliged to relinquish the establishment altogether.

After this, a Mr. Foy, who had been one of their operators at Liverpool, waited upon some of the principal manufacturers, and proposed, for a considerable premium, to erect for them the necessary apparatus, and to instruct them in the process of making the *Liquor de Javelle* at their respective works.

This proposal was acceded to by many, and the chloride of potash was for some time generally employed. The combination of potash with the chlorine has the effect, however, of weakening its bleaching power; but this is more than compensated by the circumstance of this compound being less obnoxious to the workmen than the chlorine gas alone.

In the year 1798, Mr. Tennant, of Glasgow, took out a patent for a new bleaching liquor, which was a solution of chloride of lime instead of that of chloride of potash, and which he engaged to sell much cheaper than the article that had been prepared by the foreigners; but as this was also sold in a liquid state, one of the main objections to the *Liquor de Javelle* still remained.

In order, however, to remove this objection, Mr. Tennant undertook to convey to several manufacturers, for the sum of

200*l.* to be paid by each, a right to work under his patent; and this proposal having been accepted by many of the principal manufacturers, this method of chemical bleaching was soon very generally adopted throughout the kingdom.

Some time after Mr. Tennant had made these arrangements with several of the manufacturers, some spirited individuals undertook to impugn the validity of his patent; the consequence of which was, that on the question being submitted to a legal decision, the cause went in favour of the public, and the right of patent was lost.

Since this determination, which gave great satisfaction to the whole body of manufacturers, there has been no impediment to the method of bleaching by chlorine gas; and this chemical agent was for some time prepared at most of the great works by the proprietors themselves.

The peculiar advantages of combining the chlorine gas with lime or potash, consists in this circumstance, that the saline solution gives out the gas gradually to the goods which require bleaching, but does not give it out with facility to the atmosphere. In consequence of this, the operation of bleaching is now not injurious, nor even very disagreeable, to the workmen; whereas in the former process, when the gas was merely received into water, it was given out again so freely that no man could long endure to work in it, or even for any considerable time to superintend the operation.

Now that I have ventured these remarks, the next step will be to give an account of some of the MODERN processes in bleaching, which I shall endeavour to do with as much brevity as is consistent with perspicuity. It will be most convenient to begin with the process of bleaching *linen* yarn and *linen* cloth.

In effecting this, the same methods are followed, as far as to the fourth or fifth bucking, as were formerly employed in bleaching linen long before the application of chlorine, and which have already been detailed at page 391; only good washing is resorted to instead of crofting. This being premised, the remaining operations may be described with less difficulty.

It may be asked, Why is not chlorine now employed in these first processes of bleaching linen goods? The reason is, because it would be too expensive; for there would be a greater expenditure of the chlorine gas in the removal of the filth and the resinous matter than is now incurred in the whole process, and these are all taken out in a much cheaper way by the solution of alkali and by repeated washings in pure water. The solution of chlorine is not necessary for the removal of the resin, but it is indispensable in discharging the colouring matter and the carbon.

It should be recollected, that no bleaching can ever be carried on to advantage, unless the water be pure and in great abundance. Hence Scotland seems to be peculiarly calculated for such establishments; for, there are many parts of that kingdom which abound with spring water that comes from the granite rocks nearly in a state of absolute purity.

After the fourth or fifth bucking, the goods are immersed in a solution of chloride of lime, and are then well washed by machinery in pure water. They are now carried to the souring vessels containing a portion of very dilute sulphuric acid; and when taken out of these vessels, they are again well washed in water; and lastly, they are submitted once more to the alkaline process mentioned at page 391.

This kind of goods requires at least three immersions in the solution of chloride of lime, followed by an equal number of alternate immersions in the sours and in the alkaline solution, carefully and thoroughly washing them in pure water between each of these processes. It should be remembered, however, that linens require generally a greater number of immersions in the bleaching liquor than cottons, and also that the preparation be less diluted with water.

By this method of bleaching, linen goods constantly acquire a yellowish tinge; this however is so superficial, that mere exposure to the air for a few days generally removes it. The goods are then finished by boiling them for a short time in a dilute solution of pearlash and white soap. This last operation has the effect of removing the disagreeable odour which otherwise would for a long time be attached to every article bleached by this process. It must here be remarked, that when *cotton* goods are bleached after this manner, there is no necessity for crofting; as the yellow tinge just mentioned does not appear in them when finished; any stain of that kind being completely removed by the sulphuric acid, though this acid will not remove it from linen goods.

There is a considerable trade now carried on in the bleaching of hose. The following is the process usually adopted, the accuracy of which may be relied on, as it was communicated to me some years ago by one of the partners in an extensive manufactory, who had come to London for the purpose of consulting me respecting some difficulties which had occurred in their manufactory, and which at that time were attended with considerable loss and inconvenience.

In the establishments for the manufacture of cotton hose, the stockings are first scoured in soap and water, to divest them of the oil and other impurities applied in the process of weaving;

because the weavers of cotton hose always dissolve mutton suet in melted soap, and pass the goods through the mixture. This serves a double purpose; it occasions the thread to work better, and renders the goods heavier when they are returned in a finished state to the owner.

It is in consequence of this practice that the bleacher is under the necessity of scouring such goods in a solution of soap made scalding hot; for it would be in vain to attempt to bleach them without first divesting them of this tallow, and of the dust and other impurities which will unavoidably be attached to it. To obtain this the more effectually, they are removed from the scouring vessels into pure water and thoroughly washed, the water being changed as often as is considered necessary. Many inexperienced persons, who have begun the business of bleaching and also that of dyeing, have failed of success in consequence of their not being aware of the absolute necessity there is for observing the utmost cleanliness in both these occupations.

The second process consists in boiling the hose in a weak alkaline solution, made by dissolving three pounds of American pearlash in three hundred gallons of water. When boiled in this lixivium, they are merely rinsed in clear water, and are then considered to be sufficiently prepared for being submitted to the action of the bleaching liquor. The bleacher of piece goods would consider this to be a very weak lixivium, for in that process it is not an unusual thing to dissolve the above weight of caustic potash in so small a quantity as ten gallons of water.

The bleaching liquor for cotton hose is prepared by mixing six or eight quarts of the solution of chloride of lime, in the state in which it is prepared at the still, with 20 gallons of water. In this mixture the hose are immersed, and they are suffered to remain an hour and a half or two hours. They are then taken out, and washed thoroughly in cold water.

The process of immersion in the bleaching liquid is now repeated, and this is followed by boiling the goods in an alkaline lixivium, as before. These processes of steeping in the chloride of lime and of boiling in a solution of alkali, are repeated four times alternately, and then the hose are generally found to be bleached sufficiently. The necessity there is for these repeated steepings in the solution of the chloride of lime, may be thus explained. The chlorine that is liberated decomposes a portion of the water, the oxygen of which combines with the colouring matter, and renders it soluble in the alkali.

These processes being finished, the goods are then immersed in diluted sulphuric acid, which has been so much lowered with water that it is become little more acidulous than vinegar, and may be taken into the mouth with perfect safety. This carries off

any earth or other matter not sufficiently soluble in the alkali. The steeping in this weak acidulous liquor is generally continued about three hours, though sometimes the hose are suffered to remain in it for a whole night.

It has been found, by repeated experiments, that so long as the goods are actually *immersed* in the sours, they sustain no injury; whereas, if they were taken out and suffered to become dry, their texture would be much weakened, and the damage would be irreparable. This, I have no doubt, is occasioned by the evaporation of the water, by which the sulphuric acid attached to the goods becomes concentrated and caustic.

To divest the hose of the remains of the sulphuric acid, they are washed many times in cold water, and even submitted to the action of a kind of fulling mill, called *fallers*, which cleanses these goods more effectually than could be done by any other method. But so difficult is it to remove the last portions of the sulphuric acid, that the manufacturers find it necessary, even after all this washing, to immerse them in a hot solution of soap and vegetable alkali, to finish their purification. The proportions are 4 pounds of white soap, 1 pound of best pearlash, and 150 gallons of water. This process is technically called *scalding*. This removes the disagreeable smell of the chlorine gas, at the same time that it improves the appearance of the goods to the eye, and occasions them to feel softer.

The hose are now carried again to the fallers; where they are scoured and beaten in soap and water, as before, the remains of which are perfectly washed out with successive portions of pure cold water. This is said to complete the process of bleaching.

These goods are afterwards exposed to another process called *getting up*, which is performed in the following manner. They are put into a copper of hot water, containing a weak solution of soap, with the addition of a little indigo, sufficient to give them a tinge of blue, and then they are returned to the fallers to be scoured in a still stronger solution of soap. This solution is strong enough to produce an actual lather, and the remains of it are thoroughly washed out with cold water, which finishes what is called the *cleansing* process. The whitening effect of indigo when laid on a yellow ground is very remarkable, and is well known to laundresses.

When the operator has *very fine* goods to bleach, he has recourse to a process somewhat different, which consists in immersing them in a very hot solution of soap, with the addition of a little ground indigo. The hot soap gives them a gloss which is much approved of and occasions them to handle better than common hose, and the indigo improves their colour. The common goods are immersed in indigo and water only.

When all these successive operations have been duly practised, the hose are removed to the drying stove, where care is taken that they shall be dried completely. From this they are carried to a room called the brimstone stove, where they are entirely enveloped by the vapours of sulphurous acid gas, arising from the burning of sulphur in a close chamber.

The use of this process is to decompose any portion of soap that may still be attached to the surface of the goods; for it has been found that, if they are laid up for any considerable length of time without their having undergone this operation, the smallest portion of soap remaining in them will occasion them to turn yellow. The manufacturer would, indeed, be glad to dispense with the use of soap altogether; but there is no article besides this that will effectually take away the smell of the chlorine gas.

When the hose are returned from the brimstone stove, they are slightly damped with common water, to prepare them for the finishing operation, known by the name of *dressing*. This consists in drawing each stocking separately on a stocking-leg board, in which state they are either put collectively into a powerful press, or ironed singly with a hot box-iron.

These are the methods which are generally adopted in bleaching and finishing thread and cotton hose, and they appear to be so well adapted to their respective purposes, that but very few remarks upon them will be needful.

It occurs to me, however, that the goods might be materially injured were they ever to be put into the brimstone stove in a damp state; for the vapour would then be condensed upon them in the form of sulphurous acid; and when treated afterwards with the hot iron, this acid would become concentrated and impair the texture. When the hose are dressed by the press only, it is not so necessary to attend to this circumstance. Another injury would result from this management, viz. that, being put damp into the stove, some parts would retain more water than others; and here, I conceive, dark spots would arise should the goods be laid by for a considerable time undisturbed, a circumstance which often actually happens in the shop of the retailer.

Only one thing more occurs to me, which is this, that the omission of weaving the blue and the red lines in the top of hose which are intended to be bleached, will conduce to injure the credit of the manufacturer in foreign markets¹. I propose, however, to offer a few remarks on this at the close of the Essay.

Nothing has yet been said of the method of bleaching CALICOES

¹ At the desire of a respectable bleacher in the county of Nottingham, I published a few years ago some observations on this subject in the *Tradesman's Magazine*. See vol. ii. p. 105.

for the use of the *printer*; for this embraces a great number of questions, and is a subject of very considerable difficulty. The following is the process which is generally adopted in the neighbourhood of Manchester, and throughout the county of Lancaster.

When the goods have been fired to remove the nap, as described in the Essay on Calico Printing, they are steeped for a certain time in pure water, usually until so much of the impurities is loosened from them as occasions a very sensible fermentation in the water, the time varying from twelve to twenty-four hours; or in soap and water, or in an alkaline lye which has been already used in the process of *bucking*, or bowking, as it is commonly called in this district. This appears to me, however, to be a very bad practice, because such lyes are always very dirty and loaded with resinous matter and other filth of a similar kind to that which it is the object of the bleacher to remove. Nothing but pure water, or clean lye, or good white soap and water, ought ever to be employed for these steeps. The temperature at which this steeping is conducted varies from that of 100 to 160 or 180 degrees, according to circumstances or the particular views of the operator.

The pieces are then washed in pure water; in large works this is done by means of a dash-wheel, which washes them more effectually than they could be by any other method; and then they are immediately bucked², or boiled in a solution of caustic potash, and the boiling is continued for eight or ten hours. From the boilers they are again taken to the wash-wheel, and cleansed thoroughly. The process of boiling is repeated two or three times, taking care to wash well after every operation. Each of these boilings is usually continued for the same length of time, but care is taken that the alkaline lixivium be reduced in strength at every repetition of the process. In large concerns, where the process of bleaching is continually going on night and day, the boiling is generally done in the night, and the subsequent operation of washing is performed in the day-time. After two of these boilings, some people pass the goods into the sours, whereas others do not sour them until they have been three or four times boiled.

The goods are then laid on the grass for two or three days; or, if crofting be not employed, an effect, similar to that which would be produced by exposure to the atmosphere, is obtained by an immersion in a solution of chloride of lime, of about the specific gravity of 1.005. In this they steep for twelve hours;

² For an account of the bucking apparatus, see the description of the plates which accompany this volume, and also page 391 of this Essay.

and then they are removed into sulphuric acid, diluted with about forty times its weight of pure water. Mr. Murray says that this last souring imparts a much finer whiteness to the cloth than it would acquire without this treatment, as it dissolves the remaining colouring matter which had resisted the action of the alkali and chlorine, as well as a small quantity of iron contained in all vegetable matter, or deposited on the cloth from the alkaline lyes.

After this, the pieces are washed with the greatest care in successive portions of water, and are then hung up in the dry-houses, to be dried completely for use, by a current of atmospheric air, which is perpetually passing through them.

When the operation is to be performed on fine cloth, it is usual to boil once or twice more in a still weaker solution of potash, and to finish them in strong sours, made by the mixture of one measure of sulphuric acid with 46 measures of water, or one pound of the acid to twenty-five pounds of water. This is not because fine cloths require the most bleaching, but on account of such cloth being generally used for the finest kind of printing; for the heaviest pieces are generally the most difficult to bleach perfectly. In some houses it is customary to lessen the weight of the potash one-third for every subsequent boiling.

Some printers, instead of potash, use lime water, and others even cream of lime for the first bowking; washing and souring being adopted the same as if potash were employed; but in these cases care is taken not to allow the liquor to acquire more than a scalding heat.

This is truly a cheap method; but I conceive it to be a very bad practice, because where this mode is adopted plenty of selenite will unavoidably be formed in the cloth, and nothing will perfectly remove it. It is well known to many printers whose works are situated upon rivers, that if a piece which has been thoroughly prepared, should by accident drop into the river at the time of flood, when the water is charged with earth, it would be entirely spoiled for the madder-copper. No kind of souring, nor any mode of treatment, which we are at present acquainted with, would repair the injury.

Some printers use the common potash of commerce, while others employ an alkali which has been made completely caustic by lime; others, again, mix a portion of soft soap with the potash for one or two of the first bowkings; so far are these manufacturers from being agreed as to every particular respecting these operations.

I must not, however, forget to mention that in large works, after every process of ashing, souring, or bleaching, the pieces are submitted to a powerful press, usually one of Bramah's, to

force out the chemical liquor which remains in them; and that it is from the press they are taken, either to the river or to the wash-wheel, for further purification. Some of the printers have not yet adopted the use of the press; but the professed bleachers are aware of its importance, and employ it constantly. In several works, I find it is a common practice to pass the goods through a pair of wooden rollers made of sycamore: these force out a great deal of impurity, and they make all the pieces of an equal dryness. This is not general, but I consider it to be an eligible practice, and that it ought to be performed after every operation.

Although I have now given a short account of the processes which are employed in bleaching common calicoes, or what is known in some districts by the term of *surface-bleaching*, I still consider the series of operations to be very imperfect, because the goods thus bleached are often unfit for the purposes for which they are intended, and very frequent and serious losses have been sustained in consequence of it, as every printer can testify. This is very severely felt by those who print for hire, as such printers are expected to make allowances for all imperfect work, and these are often so enormous as to absorb all the cost of materials and the expense of printing.

A knowledge of this circumstance first induced me to turn my attention to the subject of bleaching; and the hope of being able to offer some useful hints to the consideration of practical men laid the foundation of this Essay.

From frequent and repeated conversations with many of the most intelligent bleachers in various parts of the kingdom, I have, I presume, clearly ascertained that, in preparing goods for the purpose of calico-printing, the following are the most important desiderata.

First. To form such a preparation of bleaching liquid, with the respective materials so nicely balanced, that neither the salt, nor the fluid which remains after the abstraction of the chlorine, shall have any injurious effect upon the fabric of the cloth. Those who bleach with chlorine should never lose sight of the circumstance, that common muriatic acid is always produced at the moment when the oxygen of the water unites with the colouring matter; and that this acid, if not corrected by other ingredients, will have an unfavourable action on the goods under operation.

Secondly. To bleach the calicoes in so perfect a manner that each piece of every parcel shall be completely fit for madder-work; that is, when cleared after being dyed in a madder-copper, that the whites shall be uniformly good and free from those stains which the superintendants in this department of our ma-

manufactures call *spangs*. For this purpose, some manufacturers lay great stress on the use of an apparatus somewhat similar in its principle to a Papin's digester, and known by the name of a *whale-boiler*. For a description of this vessel, see the Plate No. 11. and the explanation of it at the beginning of the volume.

Thirdly. To prepare calicoes, so that they shall readily take a light and uniform shade in the blue vat.—Cloth dried in summer and in the open air, when the atmosphere is dry and warm, dips much more freely in the blue vat than that which is dried in winter, especially in frosty weather, when the pieces require more exposure. In like manner, stove-drying is never esteemed so good as tenter-drying, for any purpose of fine printing.

In dipping pale blues, the printer often sustains great loss by the pieces coming out of the vat with white streaks, so as to render it necessary to bleach them afresh, and then to appropriate them for the reception of other colours. This is occasioned by a substance existing in the cloth, which resists the action of the blue vat, and yet is not of sufficient consequence to rise to a spang when it is afterwards passed into the madder-copper.

Every man has a different process for preparing his blue-vats; therefore the want of uniformity in the shade of these colours may sometimes arise from the vats being in bad order, or it may be owing to the employment of bad indigo. I would suggest that it might perhaps be advisable to appropriate a vat of either the finest Guatamala, or of the purest East Indian indigo, entirely to the purpose of dyeing *pale* blues; and that where the style of work will allow of it, (though it often will not,) it might be worth while to try whether superior dunging, previously to the blue dipping, would prevent the evil complained of.

Fourthly. To prepare any number of pieces which shall be fit for both the above purposes, yet still be preserved perfectly sound.

It is evident to me that, in effecting these points, the main difficulty originates with the weaver; and therefore, to those who are not conversant with the business, it may be advisable to explain how this happens, before we attempt to suggest a remedy.

The weaver of calicoes generally proceeds thus. Having a fine warp delivered to him, frequently spun beyond what the staple of the cotton authorizes, and consequently not capable of bearing much hardship, he is compelled to throw in as much weft as will make the cloth of a very close texture; his only aim being to accomplish this object with the least possible trouble, and at the least expense.

As soon, therefore, as he has fixed the warp in the loom and stretched it out ready for weaving, he dresses it by rubbing it longitudinally between two brushes which have been previously dipped in a paste made of potatoes, or flour and water. This

paste is generally suffered to become sour before it is used, and frequently it is kept in an *iron* kettle till this change takes place.

When this dressing has become dry, in order to make the warp still smoother, he applies a different dressing, made with such greasy or oleaginous matters as he can the most easily procure. This generally is either tallow or butter, and is sweet or rancid as may accidentally happen; but tallow is the article which is the most commonly used, and it is applied in the following manner. The weaver having prepared a hot iron, he takes that in one hand and a lump of tallow in the other, and pressing them together, the tallow becomes partially melted and drops in patches on various parts of the warp. This is afterwards dispersed and spread over the whole warp, by means of the brushes which were employed to spread the paste before mentioned.

Instead of tallow, why might not soft soap be employed? It would be desirable for some manufacturer to give this a fair trial. Should it answer the weaver's purpose, it might afterwards be readily removed by washing.

It will be manifest to those who have considered this mode of procedure, that the subsequent spreading of the tallow cannot be effected without the grease being left in the largest quantity on those places where it was first applied. Accordingly, it is found that these spots are often particularly discernible when the goods come to be dyed, although the operator may have supposed that they were well cleaned, having undergone the usual routine of steeping, boiling, souring, bleaching, washing, printing, and dyeing. For an account of some methods for examining the goodness of the bleaching of white calicoes, see the Essay on Calico Printing.

Printed calicoes are also often stained in larger blotches, though not so conspicuous as those just mentioned, but evidently arising from grease; generally covering a larger portion of the cloth, and very difficult to be removed. The workmen distinguish these by the name of *copper* stains, supposing them to have arisen in the madder-copper from an unequal application of the heat. This, however, is undoubtedly an erroneous opinion.

In reviewing the preceding observations the following questions suggest themselves.

If grease be the chief impediment to perfect bleaching, what are the best means of removing it? Are any of the alkaline solutions we have mentioned, capable of effecting its removal? In answer to this query, I would say, Take caustic potash, properly diluted with water, and not the *dirty* waste lye, an article often resorted to. For, in preparing for fine madder-work, I am confident that what is considered to be a cheap, economical, and, I

may be permitted to add, dirty mode of bleaching, can never do. On the contrary, for such work, the most expensive bleaching will generally prove to be the cheapest eventually; for the pieces have a better chance of being perfect, and the dyeing materials will go further.

Is soap (either soft or hard) of any service in the process of steeping, or that of boiling? Is lime of itself a solvent for grease? If lime should be found to be adequate to this purpose, is there any probability of its injuring the texture of the cloth when used in the manner already described? And is there not some danger of particles of this earth remaining in the cloth after the most careful washing, and of its forming a sulphate of lime by immersion in the sours.

When goods have turned out spangled, is it advisable, in order to prevent a repetition of the evil, and will it be consistent with the preservation of the texture of the cloth, to have recourse to more of the alkali, to greater heat, or to more frequent boilings? Or is any other plan preferable to all or any of these? Where perfect work is required, I conceive the proper answer to this query to be this. Let the alkaline lye be reduced in strength, and then let the usual number of boilings be doubled. That is, let them be boiled at least seven or eight times.

On the principle of boiling in a vessel somewhat analogous to a Papin's digester, what degree of heat can be employed with safety to the cloth? It will be seen, that in the common process of boiling the pieces, the lye being weak and exposed to the pressure of the atmosphere it can never much exceed the temperature of 212° .

What is the substance contained in cotton which resists the action of the blue-vat, or of cold water, and yet does not act as a mordant in the madder-copper? I am disposed to think that this is a question which, in the present state of chemical knowledge, no one is able to answer, although it is well known to every printer of the present day, that such a substance does exist, and that it often occasions much trouble and perplexity.

What is the cause of those marks called copper-stains, already noticed? Are they owing to a portion of alkali being left in the cloth during the operations of bleaching, or may they may be ascribed to insufficient washing after the process of dunging? These are certainly not copper-stains but are possibly owing to improper bleaching. It is likely, indeed, in most cases, that these would not have appeared, had the bleaching been prolonged or the different operations oftener repeated.

The whole of these questions seem to arise naturally from a due consideration of this subject, and all of them, I believe, have at one time or other been proposed to me by various practical men, for my opinion; a circumstance which convinces me that

much remains to be done before the art of bleaching calicoes for the use of the printer shall have attained that degree of perfection of which many other arts can already boast.

When the process of bleaching by chlorine was first practised, the art of calico-printing may be said to have been in its infancy, and consequently very little variation was then made in the operation of bleaching the brown pieces, whatever might have been the style of work for which they were intended. When the competition was less, the perfection of bleaching was comparatively of small importance. But now the case is materially altered, and all the best printers know, that the common routine of processes, and such as I have described at page 404, is insufficient for bleaching calicoes which are designed for best madder-work. The common mode of bleaching is not sufficient, because goods so treated are never fully bleached *internally*; and, therefore, when they come into the madder-copper, the remaining impurities will in some measure rise to the surface, and there becoming a mordant for the madder, will occasion those parts of the cloth, which were intended to be preserved white, to acquire an indelible stain, or at least will inevitably produce what are called dull whites.

To remedy this, nothing will prove effectual, I suspect, but to increase the number of the operations, as mentioned above, and to conduct every process with the strictest regard to cleanliness, and to the purity of the articles employed. Here I had more particularly in mind the practice of using old dirty alkaline solutions; but it will also be equally impossible to produce fine bleaching where the goods, at all times of the year, can be washed only in a river; because in time of flood the water will be charged with calcareous earth, which afterwards, when they are immersed in the sulphuric acid, will form an insoluble selenite within the pores of the cloth.

Knowing that a great deal of very excellent bleaching is accomplished in Scotland, I have procured from a scientific printer in that part of the kingdom, an exact account of the plan he pursues whenever he bleaches calicoes for madder-work, or resist-work, or for the fine pale blue-dipping, and which he assures me I may recommend with confidence. The following concise outline of the process will, I trust, be sufficiently explicit to be understood by every practical man.

The goods having been singed and steeped in pure water, as is customary in common bleaching, they are passed through a pair of rollers to press out the impurities which have been loosened by the steeping. It must here, however, be observed, that where the expense of one extra dyeing can be afforded, the process might be very much improved by steeping the brown calicoes for thirty or forty hours *before* singeing, because this would separate much

of that impurity which usually becomes fixed in the stuff on its being passed over the hot cylinders. When the pieces have been thus singed, steeped, and pressed, they are boiled four times, ten or twelve hours at each time, in a solution of caustic potash, of the specific gravity of from 1·0127 to 1·0156, washing them carefully and thoroughly in pure water between each of these boilings. They are then immersed in a solution of the chloride of potash, originally of the strength of 1·0625, and afterwards reduced with twenty-four times its measure of water. The specific gravity of the chloride of lime or of potash, is not an absolute rule for the determination of the bleaching power of either; for, sometimes the specific gravity will be what it ought to be, and yet the liquor, owing to the impurity of the materials, will be nearly effete. For this reason, the solution of indigo is generally employed to ascertain the goodness of all bleaching liquors. When the preparation is good, the proportions mentioned above will whiten cotton goods completely in eight hours. In this preparation they are however generally suffered to remain twelve hours. It is of importance to remark, that here the common bleaching liquor (chloride of lime) cannot, without injury, be substituted for chloride of potash.

Some printers take the pieces from this solution, and, while wet, lay them on the grass, and there expose them to the sun and weather for two or three days. From thence they are removed to the sours, made of the specific gravity of about 1·0254 at the temperature of 110 degrees of Fahrenheit. In bleaching common goods, and such as are not designed for the best printing, the specific gravity of the sours is varied from that of 1·0146 to that of 1·0238, if taken when they become of the temperature of the atmosphere. In these they are suffered to lie for five or six hours, after which they are taken to the wheel and washed thoroughly. When this operation is finished, they are submitted to four more boilings as before, with a solution of caustic potash; taking care to wash well between each of these boilings. Sometimes *pearl-ash*, made caustic, is used for the last of these boilings, lest the sulphur, which always exists in the potash of commerce, should impair the whites. They are then immersed in the diluted chloride of potash, of the strength before mentioned; after which they are well washed in pure water, and then winched for half an hour in common sours. The last process is that of careful washing in plenty of clean water, after which they are not put into the stove, but are immediately hung up in the airing sheds to dry gradually. I know several print-works where it would be impossible to produce fine bleaching, because they are not supplied with a sufficiency of water. For this purpose the water must be good, and there ought to be plenty of it at all seasons.

The number of operations, as here described, is great; but I know of no other mode of procedure by which perfect bleaching is so likely to be effected at all times and in all seasons, without disappointment. It must here be remarked, that, for the best purposes of printing, it would not be sufficient to take goods which have been bleached in the common way and finish these by the better process; because the selenite deposited in the cloth by that operation, will for ever spoil them for madder colours; at least, a printer who is curious in his work would not dare to use such for those purposes.

Whilst I am upon the subject of bleaching, it will be necessary to mention that print-clearing powder, which is chloride of lime mixed with about one-tenth part of its weight of carbonate of soda, is now employed in clearing the whites of maddered goods, and that this has almost entirely superseded the operation of crofting, which was a tedious and expensive process. The method is to mix a small portion of the powder with a large quantity of warm water, and then to suffer the maddered pieces to lie in this preparation till the grounds become perfectly white.

This, which is one of the last improvements in calico printing, is of very considerable importance; for, the finest gingham, as they are called, and the most expensive chintz work, which contain a variety of very delicate colours, and formerly required many weeks exposure on the grass, can now be cleansed in a few hours, so as to produce the most perfect whites, without impairing any of the colours themselves.

In conducting this process, it is of the utmost consequence to attend to the precise strength of the preparation of chlorine, that it may be strong enough to clear the whites completely, and yet incapable of discharging or impairing any of the printed colours. This is usually ascertained by means of a very dilute solution of sulphate of indigo, prepared in the following manner.

One pound of the best Spanish indigo that can be procured, is to be dissolved by the usual method, in four pounds of concentrated sulphuric acid. These proportions will generally saturate each other. When the whole of the indigo is dissolved, one part by measure of this solution is to be diluted with sixteen parts by measure of water, and then it will be fit for use. To obviate any deception which might arise in case of a difference in the quality of the indigo, it is always best to preserve some of the old solution, and then, having compared the new with this, to alter the proportion of water a little, if this be found necessary. The quantity of water which is employed in diluting the solution of indigo is not very material, provided the operator accustoms himself to the use of one certain determinate proportion; and indeed this test is used of various degrees of strength according

to the fancy of different printers; but one printer should always use it of one particular strength.

The object in making this preparation is to have a standard always at hand, by which the printer can with precision ascertain the exact strength of any of his bleaching liquor; and this is always to be determined by the quantity of it that is required to destroy the colour of any given portion of the test, or *vice versâ*.

In employing this reagent, it is customary to have two long graduated glass tubes, in one of which the diluted sulphate of indigo is put, and in the other the bleaching liquor. By gradually pouring some of the former into the latter, it is immediately seen how much of the coloured test is destroyed, by a given number of parts of the preparation of chlorine. This, however, for the reasons already adduced, is not a sufficient test of itself for ascertaining the goodness of a bleaching liquor without attending also to its specific gravity.

The compressed steam of boiling water has been lately employed instead of chlorine in bleaching cottons. It is said that this method of bleaching has long been practised in some parts of the East. Chaptal was the first writer who recommended it to the European bleacher¹. By the continued and alternate immersion of cotton goods in an alkaline liquor, and the exposure of them to the action of the vapour arising from the same lixivium when heated to 220° or 230°, the goods are said to be whitened very effectually without the fabric sustaining any injury. The resinous and other colouring matter of the cloth, which is insoluble in a dilute solution of alkali at the temperature of boiling water, becomes soluble in this menstruum, when heated a few degrees beyond that point. The operation consists, first, in immersing the goods in the alkaline lixivium, and then exposing them to the heated aqueous vapour; and these methods are pursued alternately till the whitening is completely attained.

This mode of bleaching linen goods has been adopted in France for domestic washing. Chaptal tried it on 200 pair of sheets belonging to the Hospital of the Hotel-Dieu of Paris, with the utmost success. The linen was perfectly cleansed, and the expense was reduced in the proportion of four to seven². I have had no opportunity of observing the effect of this process myself: but I can easily conceive that a superior temperature may be of service in bleaching, because I have noticed that when brown calicoes, which have undergone only *one* boiling, have lain all night in the

¹ See his *Chemistry applied to the Arts*, vol. iii. p. 100. Delam  therie also wrote a memoir upon it in the *Journal de Physique* for the year 1801, at p. 305, of which some account may be seen in Nicholson's 4to *Journal*, vol. iv. p. 469.

² For the details see *Annales de Chimie*, tome xxxviii. p. 291.

kier, or whale boiler^s, those parts of the pieces which had been in immediate contact with the iron fountain, standing in the middle of the apparatus, were quite white, while the others were very little improved in colour by the operation. This I attribute to the lengthened continuance of a high temperature, as a great degree of heat is always communicated to the middle of the vessel, by the constant circulation of the boiling liquor through the fountain, the metallic part of which, at times, may perhaps exceed the temperature of 212°.

The bleaching of linen and cotton goods by means of compressed steam, will however be always attended with some difficulty on account of the danger of the bursting of the apparatus by the force of the confined vapour, if the valves should ever be improperly loaded: but, notwithstanding this objection, it appears to me that the practice deserves further investigation; for it would doubtless be a great advantage to the arts, if it were possible to bleach our manufactured goods in as short a time as they are at present finished, and yet save the expense of chlorine altogether. The apparatus employed for this purpose in Great Britain is generally made with large slabs of stone cramped together with iron, and sufficiently massy to sustain the effects of great pressure.

It was originally my intention to have offered some remarks on the methods of bleaching wool and woollen goods, silk, beeswax, writing paper, books, prints, &c.: but as the Essay has already exceeded its prescribed bounds, I must content myself by merely referring the reader to the sources from whence he may obtain some information on these subjects.

Wool has usually been bleached by the fumes arising from the slow combustion of sulphur, an article which was employed sixteen hundred years ago for the same purpose. It has, however, been found that this mode only whitens the surface of the goods: therefore, of late years, recourse has, in some instances, been had to the *liquid* sulphurous acid, which bleaches wool more effectually than that acid does when in a gaseous state. Some account of the usual process by the means of sulphurous acid gas, may be seen in Pajot Des Charmes' *Art of Bleaching*, translated by Nicholson, 8vo. London, 1799, page 280. The burning of brimstone in atmospheric air is called the *slow* combustion, in opposition to the burning it in oxygen gas, or by the mixture of nitre; but Stahl has shown that in bleaching woollen, the more slowly the sulphur is burnt, the more effect will it produce. Apuleius, who lived in the time of the Antonines, tells an anecdote

^s For an explanation of the nature of this apparatus see the description of the plates.

dote, in the Romance of the Golden Ass, of a fuller who unexpectedly bringing home a friend to sup with him at the instant when his wife was engaged with a gallant, she on the sudden alarm hides him in the wicker apparatus which had just been employed to bleach garments by the fumes of burning sulphur. Presently, while they are at supper, the gallant stifled with the fumes sneezes aloud; the fuller removes the coop, and the poor, panting, half-smothered culprit is discovered.—It appears from this story, that the ancient fullers bleached their woollen cloths by hanging them round an apparatus made of wicker work, and then setting fire to a portion of sulphur placed underneath it. Messrs. Roland, Laplatiere and Allard, who were general inspectors of manufactures in France, published several memoirs on the bleaching of wool, and the above account by Charmes appears to have been taken from these papers.

In bleaching bees-wax the following is the process, as it is usually conducted in England. Common bees-wax is melted upon hot water; and when in a fluid state, it is laded out of the copper, together with a part of the water, into a wooden vessel, and in this it is allowed to remain a few hours for the impurities to subside from it. The purified wax is then put, while still hot, into a cullender full of holes, through which it runs, and falls upon a revolving metallic roller, which dips into cold water contained in a vessel placed underneath. As the melted wax runs through the cullender upon the revolving roller, the motion of the cylinder forms it into thin shavings, which cool as they come in contact with the water, and fall in an accumulated heap into the water below. These shavings of wax being now in a suitable form for absorbing oxygen, they are taken out of the tub, and exposed in a field to the action of the atmosphere till they become sufficiently white.

A memoir by Baumé on the bleaching of silk will be found in Nicholson's 4to Journal, vol. i. pp. 32 and 88. This memoir, which is extremely interesting, was first published in the Journal de Physique, tom. xlii. p. 376, &c. The method consists in digesting the silk in a large quantity of spirit of wine previously mixed with a few ounces of muriatic acid. Some account of the bleaching of bees-wax may be seen in Fourcroy's System of Chemistry, vol. x. p. 483.

The specifications of several patents which have been obtained of late years for divers modes of bleaching paper, may be read in the Repertory of Arts: and ample directions for bleaching old copper-plate engravings and old printed books, will be found in Chaptal's System of Chemistry applied to the Arts, vol. iii. p. 108. A memoir by Loysel on the bleaching of pulp for making paper may be seen in the Annales de Chimie, tom. xxxix. p. 137.

The art of bleaching has also been introduced of late years into the straw manufactory. The manufacture of straw into the form of hats for females has become very considerable, and consequently important, especially as it gives employment to a very great number of the children of the poor. I have not yet learned the methods employed for bleaching the straw when it is intended for *white* hats, but a friend of mine has assured me that the *sulphurous acid* is employed.

I have now only to make a few desultory observations which I conceive may be useful, and with these I shall close the Essay.

In a large bleaching establishment it is of great importance to know how to procure manganese of the best quality. There are several mines of this mineral in various parts of these islands, of very variable qualities. Many kinds are of little value to the bleacher, inasmuch as they require a larger portion of sulphuric acid and yet produce less oxygen. Those, however, which contain the largest proportion of the crystallized oxide are generally to be preferred.

Being desirous of obtaining the best information respecting manganese, I took an opportunity, in the year 1810, of visiting the celebrated mine of Upton Pine in the county of Devon, where, from the proprietors themselves and from some of the intelligent inhabitants of the neighbourhood, I learnt several particulars which may be worth recording.

This mine is situated between the two turnpike roads from Exeter to South Moulton and from Exeter to Crediton, and, as far as I could collect, had then been worked about forty years; though at first the quantity of the manganese that was raised was small, as it was then employed only in the manufacture of glass, and in some processes in the Staffordshire potteries. This mine was accidentally discovered by a person passing along the road; as the mineral originally came out at the surface of the ground, and the roads in the neighbourhood were occasionally repaired with it.

Some thousand tons of manganese and loose earth having been removed, the mine is now in such a state as to allow persons to descend into it by a winding path cut within the hill, and which conducts to the foot of a perpendicular rock fifty feet high. The entrance into that part of the mine which is now worked is through an archway cut in the face of this rock. An immense quantity of manganese having been raised since this entrance was made, the excavations are now of considerable extent, the upper ground being supported by large masses of manganese which are left for pillars. Here, by help of a pick-axe, I broke off some fine specimens of the mineral.

At some distance from the entrance of which I have been

speaking, two shafts are sunk of the depth of fifty feet each, which lead to the lowest part of the mine, and which I was desirous of exploring, as I could distinctly hear the men at work under my feet: but being told that I could not descend without being thoroughly wet, and having no dress with me fit for the undertaking, I was induced to decline the offer which the superintendant made of accompanying me. In order to drain the mine as well as possible, without an engine, they sink as low as they can in the first instance, and then work *upwards* to get the mineral. The part which I explored is 50 feet below the surface of the ground, and the part they were then working is 50 feet lower still.

The captain of the works informed me that the lode runs north-east and south-west; and from his account I calculate that it dips regularly at an angle of 40 degrees. In some places the vein is twelve feet thick, in others not more than two feet. The capel, as they call it, which covers the mineral, is a hard rock composed of a mixture of sand, red clay, and manganese.

It was usual with the bleacher, to cast away the residuum of the stills as a worthless article; but it is now consumed in large quantities by the manufacturers of carbonate of soda, who decompose the alkaline sulphate by means of carbonaceous matter and lime in reverberatory furnaces, and obtain the soda very pure and in beautiful large white crystals. It is also used largely in making Glaubers salt, which is effected simply by dissolving the residuum, decomposing the salts of manganese, and precipitating the oxide of that metal by means of lime, filtering the clear solution, evaporating it to the proper strength, and then setting it by in shallow vessels to cool and crystallize.

M. Humboldt has found that seeds which do not commonly germinate in our climates, and which of course we cannot hope to naturalize, become capable of doing so when immersed for some days in a weak solution of chlorine; and I am anxious to remark, that gardeners, whose grounds are in the neighbourhood of bleach-fields, would do well in availing themselves of all the advantages their situation affords them for making experiments on this interesting and important subject.

In bleaching with chlorine, it is of consequence to expose all the surfaces equally, and in proper succession; for, when the goods lie one upon another, the gas does not properly penetrate them, and they are never uniformly bleached: whereas, in the bucking process, with the solution of potash, they are disposed as it were in masses of a considerable thickness, and the operation still goes on well. It was probably the knowledge of this circumstance which has induced many bleachers to have their vessels constructed very broad and shallow; but this has occasioned another very serious inconvenience. The chlorgdes bein

more liable to lose the chlorine the greater the surface of the apparatus be in which the liquors are exposed, it is more difficult for the men to secure themselves from injury, and the waste is much more considerable. Where there is a contrivance for exposing all the surfaces equally to the action of the bleaching liquor, the *deeper* the vessels are in comparison of their diameter, the better will they be adapted to convenience and economy.

It is also important to rinse the goods immediately after they come out of the alkaline liquor. It is no unusual thing for the manufacturer to allow them to lie in heaps for a considerable time before washing. But this I conceive to be a bad practice; for while the goods are warm the pores are open, and the filth which has been loosened by the recent action of the alkali, will be more effectually removed by washing *immediately* than if they be allowed to lie till they become cold.

In order that no waste of alkali should arise in the process of boiling or bucking the calicoes, it has been customary with many persons to use the lyes a second and a third time, and often to the great injury of the goods which are so treated. Instead of this, I would advise, that all such impure lyes should be concentrated by evaporation, and, when of a due consistence, removed from the evaporating pan to the floor of a small reverberatory furnace similar to that described in the plates. Where there is a convenience for fully concentrating such waste lyes by evaporation, a common baker's oven might be employed for the subsequent calcination, provided the precautions were taken in heating it which are advised by Pajot des Charmes, p. 87 of his well-known work on this subject. In such a furnace they would easily be purified, because a gentle calcination would burn the colouring matter and restore the alkali to its original state. In districts where coal can be had cheap, and the consumption of alkali is considerable, this would be a very economical process.

Nothing now remains but to redeem the pledge which I gave at page 404, to offer a few remarks on the introduction of the blue and red stripes, which are often seen at the top of cotton hose. But these remarks must be very brief.

Although the bleacher of hose may easily determine the real quantity of bleaching liquid to be used, yet there is still considerable risk in the process, and a danger of the texture of the articles being in some measure injured if the operation be conducted with carelessness, or by those who are unacquainted with the properties of the bleaching liquor. On this account, therefore, it is desirable that the public should be acquainted with a test that would in every case show, whether the chemicals had been properly applied or not; or, in other words, whether the goods

which an individual may be about to purchase, have or have not been impaired by the process of bleaching.

The makers of thread and cotton hose were so convinced of the importance of having a test of this kind, that some few years ago the principal manufacturers adopted the practice of running a line of vat-blue thread dyed very dark, or of Turkey-red, along the top of each stocking; and those bleachers only were employed by them who could render the hose beautifully white, without effacing the blue or red stripes, or even lessening their intensity of colour.

The chloride of lime will destroy indigo-blue or the Turkey-red dye, if it be used of a considerable strength; and yet it may be so diluted, that it will be strong enough to bleach linen or cotton goods effectually, and still be incapable of injuring the colours above mentioned. On this account it appears to me that these dyes will always afford excellent tests for ascertaining when the bleaching process has been properly or improperly conducted.

Great advantages might indeed accrue to the manufactures of this country if the makers of plain calicoes, dimities, hempen cloths, cambrics, and Irish linens, as well as the makers of cotton hose, would adopt the method of running a line of such coloured threads along one of the edges of their goods, before they send them to be bleached; and that they would employ no bleacher who would not engage to preserve those colours entire, and of their original perfection or intensity.

This expedient can never be of use for printed cottons, because the varied processes to which white calicoes are usually submitted by the printer, would inevitably destroy the indigo-blue, and probably the Turkey-red line also. It can be of use as a test of good bleaching only, when the goods are intended to remain white.

The following are some of the sources from whence further information may be obtained on the subject of this Essay. "Additions to the Description of the Bleaching Process in France," by M. Berthollet, tome vi. of the same work, page 204.—"A Letter from M. D. Hellancourt to M. Lavoisier, giving an Account of the Method of bleaching Cloth in Beauvoisis in Flanders, and in Lower Picardy," tome vii. page 263–277.—"Memoir on the Distillation of Manganese with Sulphuric Acid," by Vauquelin and Bouvier, tome vii. page 287.—"The Manner of preparing at all times, and in all places, and at little cost, a saponaceous Liquor for whitening Cloth." Pelletier, tome xix. page 349.

ESSAY XIII.

ON WATER.

IN the beginning of the last century it was supposed, that there were four elementary bodies in Nature, and that this terrestrial world was entirely composed of those elements. Of these first principles, WATER was one; and consequently this was always considered to be a simple substance that entered into the composition of most other bodies, but was itself incapable of decomposition.

The ancient Persians looked upon water as the principle of all bodies, and many other ancient nations considered it to be the first principle of all created things. Milton likewise favours the idea :

————— “ On the watery calm
His brooding wings the spirit of God outspread,
And vital virtue infus'd, and vital warmth
Throughout the fluid mass.”—*Parad. Lost*, book vii. line 234.

The same doctrine is also taught in the Koran. “Do not the unbelievers therefore know that the heavens and the earth were solid, and we clave the same in sunder, and made every living thing of water?”—Sale's *Koran*, vol. ii. p. 155.

Of late years, however, it has been discovered that this notion of the simplicity of water is erroneous, and that the four substances which the ancients had fixed upon as the simple elements of Nature are themselves all *compound* bodies.

Water is composed of oxygen and hydrogen in the proportions of 8 parts by weight of the former to 1 of the latter; so that 8 ounces of oxygen gas when united with 1 ounce of hydrogen gas will form 9 ounces of water. Some experiments by Ritter seem to prove that *frozen* water contains a less proportion of oxygen. These were communicated by Professor Jameson to Mr. J. Murray, who has given an interesting account of them in the 2nd volume of his *System of Chemistry*. The most beautiful, and apparently the most decisive of these experiments, is that of diffusing in various portions of water a quantity of newly prepared white prussiate of iron, (a substance which, by the blue colour it assumes when it receives oxygen, is a very delicate test of that principle,) and excluding the action of atmospheric air by a thin

layer of oil on the surface of the liquid. These vessels were exposed to various degrees of cold, and as soon as the water in either of them froze, the *white* precipitate became *blue*.

Since the compound nature of water has been understood, many ways have been discovered of decomposing and re-forming it from its original elements, so that there is now no longer the least doubt either of its composition, or of the proportion of each of the elements of which it consists.

Water may be decomposed by the agency of some combustible substances; also by means of common Voltaic electricity. Vegetables of all kinds, while alive and fresh, are likewise furnished with organs for the decomposition of water, by which they appropriate its hydrogen and part of the oxygen to the formation of oil, sugar, starch, and numberless others of the combinations to which we apply the term *vegetable* principles.

Fish, especially those of the cetaceous tribe, constantly decompose water and live upon its hydrogen. We have also reason to believe that some terrestrial animals are endowed with the same faculty. Count Rumford in his *Essays*, vol. i. p. 194, has very satisfactorily shown, that the surprisingly small quantity of solid food which is sufficient for nourishment when converted into rich and palatable soup, is owing to the culinary process having prepared the water for decomposition, and that this is ultimately effected during the act of digestion. I suspect that tainted wooden vessels have the property of decomposing water. It is related in the *Philosophical Transactions*, that a company of English who had provided themselves with good wholesome water at St. Jago, which was put into hogsheads, found on their arrival at the Island of Borneo, that the water was become exceedingly fetid, and that it emitted a vapour which caught fire on a lighted candle being brought near it. An account of a similar change in some water taken from the Thames, may be seen in the same work, No. 268, p. 838. It is a curious fact, that if an electric spark be passed through oxygen and hydrogen gases, whatever may be the proportions of the mixture, 8 parts by weight of oxygen and 1 of hydrogen will be the only proportions that unite to form water, and that the remainder will still continue in the state of gases.

There can be no doubt that water is also decomposed in many of our chemical processes, and that the effects which are produced in some of our manufacturing operations are owing entirely to the same cause. I will adduce one instance.

Considerable advantage is derived by the woollen-dyers from the use of water in the preparation of rasped logwood. As the wood is cut into chips, they sprinkle it abundantly with water, and in that moistened state it is thrown into large heaps, and sometimes into bins of great size, where it is suffered to lie

as long as is convenient. By this treatment the chips become heated, or they ferment as the dyers call it, and thus undergo a very remarkable change; for, after having lain a few months in this state, they give out the colouring matter in the dyeing copper much more easily; and any given quantity of such chips will produce a more intense dye than could have been obtained from an equal quantity of chips which had not been thus treated. It is difficult to account for this, unless we suppose that the water becomes in part decomposed, and that its oxygen, uniting with the vegetable colouring matter, renders it more intense,—similar to the case of fruits, which deepen in colour as they ripen, by their gradual absorption of oxygen.

From the observations which I have made during the superintendence of a variety of chemical processes, I think I am justified in asserting that, whenever this subject comes to be thoroughly investigated, it will be found that water has more to do in influencing the results of most of the operations of nature and art than has generally been imagined. This will perhaps appear probable, when it is considered that water is a solvent for the alkalies as well as for almost all saline bodies, acids and earths; and that by its decomposition it often imparts oxygen to one principle and hydrogen to another.

It is from this idea that I am induced to fix upon water as one of the subjects of these Essays, with a view of directing the attention of our various artists and manufacturers to this one particular point.

The subject is so important, and embraces such a variety of matter, that it would be impossible in the course of a short essay to enter into that amplification of detail which the matter deserves. A history of the different opinions respecting water, and of the progress of the various discoveries in this branch of natural philosophy, will therefore not be expected; but if such evidence can be adduced as will be sufficient to convince the inquiring reader that the most common fluid we have, and that which is the least thought of, is capable of effecting the most important changes in the materials on which he operates¹, or of producing results which will at times disappoint all his expectations; something will be done towards informing the public mind, or, at least, the young manufacturer will be furnished with an idea that may be of use to him in the conduct of some of those processes which it will be his business to superintend.

Water exists in four separate and distinct forms, viz. in the

¹ Scheele dissolved even glass by boiling a small quantity of distilled water for several days in a matrass made of that material.—See the Preface to his *Treatise on Air and Fire*.

state of ice; in that of a fluid; in the state of vapour; and in a state of chemical combination with other bodies.

The most simple form in which it is probable that water will ever be exhibited, is that of ice; for by the mere combination of ice with caloric fluid water will be formed, and a further portion of caloric will convert this fluid into steam, the most attenuated aqueous vapour being nothing more than ice dissolved and rarefied by the solvent and expansive power of caloric.

Besides these different appearances of water, which are familiar to every one, water is known to exist in chemical combination with other bodies, forming an essential part of their substance, and contributing towards the semblance, forms and qualities which they respectively exhibit; but in these cases it undergoes so considerable a degree of condensation, that it loses all the common characters of water. The water, in these instances, unites in certain definite proportions, and such compounds are known to the modern chemist by the name of *hydrates*.

Some students at Florence having provided a hollow globe of gold, filled it with water and then submitted it to the action of a very powerful press: but they were not able to produce any condensation of the fluid whatever, though the press was sufficiently powerful to occasion the water to exude through the pores of the metallic vessel in which it was inclosed¹.

Canton long ago proved the expansibility of water; but Mr. Jacob Perkins has lately contrived an instrument which he calls a Piezometer, in which he has subjected water to a pressure of 326 atmospheres, and has succeeded in increasing its density 3.5 per cent². Nature however, as has already been hinted, effects the condensation of water in many of her operations, and it will be sufficient to establish the truth of the assertion just to mention a few examples.

It is an axiom in chemical science, that bodies in acquiring condensation give out caloric³. Thus water always parts with caloric in the act of freezing, though it takes such a form during its crystallization as disguises the actual condensation of its parts, and occasions a diminution of its specific gravity. But water thrown upon quick lime gives out more heat than it does in the act of freezing: consequently it becomes more condensed when combined with the lime, than when it exists in the state of ice.

If a hot saturated solution of sulphate of soda be corked up in a glass bottle containing a thermometer, and then laid aside to

¹ *Essays of Natural Experiments made in the Académie del Cimento*: Waller's Translation, 4to, London 1684, page 203.

² *Quarterly Journal of Science*, vol. x. p. 399.

³ The constant rise of temperature in the atmosphere after rain, is owing to the aqueous vapour giving out caloric while it is changing into water.

acquire the temperature of the atmosphere, the solution will cool without the salt crystallizing. When the whole has become sufficiently cold, and the degree noted at which the mercury stands in the thermometer, if the cork be then removed to admit the atmospheric air, the salt will instantly shoot into crystals, and the mercury will rise in the thermometer several degrees. What can this rise of the thermometer be owing to, if it be not to the water parting with its caloric as it unites with the sulphuric salt and becomes condensed in the newly formed crystals?

This salt, which will preserve its figure and solidity so long as it retains this water in its composition, will become smooth and pulverulent, when it loses the water of crystallization, by exposure to the action of the atmosphere. Those who are conversant with salts well know, that some lose the water of crystallization and effloresce, while others absorb water and deliquesce, by exposure to the atmosphere. Sulphate of soda, borate of soda, sulphite of lime, and phosphite of soda, belong to the first; and muriate of lime, muriate of magnesia, and nitrate of lime, belong to the latter of these classes.

Sometimes one salt will rob another of its water of crystallization. Thus, crystallized muriate of lime will take the water from the crystals of carbonate of soda. If both salts be inclosed in the same vessel, and yet not in contact, the carbonate of soda will fall into powder and the muriate of lime will become fluid.

Not only the artificial but also the natural salts, whether they be earthy, alkaline or metallic, are chiefly indebted to their respective portions of water for their transparency, for their crystalline appearance, and even in part for their solidity.

Few of the saline productions of nature are better known than sulphate of lime, or common plaster of Paris, which when taken out of the earth is a substance very hard and compact. For the use of masons, statuaries, and some other artists, this earthy salt is broken into small pieces, and then submitted to the heat of a common oven to dissipate so much of the water of its composition as can be separated by this means. After this operation, the sulphate of lime may be easily reduced to the state of a soft impalpable powder.

When the plaster which has been thus prepared, is to be used, the workman, in order to give it its original solidity, mixes it with a certain portion of water, and then pours it hastily into moulds, to form statues, busts, cornices, or other ornamental work for which it is generally employed. In this instance the dried plaster has such an affinity for water and a capacity to regain what it had lost, that it instantly attracts and condenses a very considerable quantity, and the whole becomes changed into one entire and very compact mass.

Pure alumina has a similar affinity for water, and the union is so intimate that it is almost impossible ever to separate the water with which it has been united. Saussure, who made experiments on this subject, declares that this earth has so powerful an attraction for water, that it will retain a tenth of its weight of that fluid, even though it be submitted to a heat that will fuse iron.

Potash after having been submitted to a red heat is found to retain more than 13 per cent., and soda nearly 19 per cent., of water. According to the analysis of D'Arcet, the proportion of water is even greater than this.—*Annales de Chimie*, tom. lxxii. p. 96. and lxxiii. p. 175.

Seeing then that water has so great an affinity for many bodies, and that it imparts transparency to one and hardness to another, it is surely worth while to examine whether it may not fulfil an important office in some mechanical and manufacturing processes in which its operation has been least suspected.

If a perfectly compact crucible be well filled with dry chalk, and then submitted to the strongest heat that is usually raised in a common fire-place, it will be extremely difficult, if not impossible, to convert the whole of the chalk into lime. But if a hole be perforated in the bottom of the crucible, and this fixed in a situation where a current of aqueous vapour, or atmospheric air, can freely pass through it, the carbonic acid will be separated, and the lime completely formed, in less time and with less heat than it could have been effected at without such an accession. The water aids the separation of the carbonic acid, and enables it to pass off in the form of gas. This fact was first communicated to me by Mr. Dalton of Manchester; and my own observations have since confirmed the truth of his statement.

Our common lime kilns are all built with an opening at the bottom, for the removal of the lime when burnt. This allows of a constant current of atmospheric air through the whole mass of stone, and consequently a considerable portion of water is conveyed to it during the whole progress of the operation. I would therefore suggest to the burners of lime, that it may be worth while, whenever they draw the contents of a kiln not sufficiently burnt, (which often happens,) to notice whether the atmosphere had not been in an unusually dry state at that period, and whether the imperfection of the lime should not have been ascribed rather to this than any other cause.

Should this be found to be the case, the inconvenience might be obviated by placing a broad vessel of water at the mouth of each kiln; because the heat of the kiln would occasion a constant evaporation from its surface, and the current of air which sets through the kiln would convey the aqueous vapour to every part.

In like manner, there is reason to believe that quick lime would

not combine with carbonic acid, however long it might be exposed to its action, provided water were not present; and that the mortar or cement employed in buildings would never acquire the hardness of which it is capable, were it not for the gradual absorption of the water of the atmosphere.

Vegetable fermentation cannot take place without water; and I suspect that the excellence of wine and all other fermented liquors depends in a great measure on the proportion which the water bears to that of the sugar and the mucilage. The perfection of the process of malting, as is well known to all good maltsters, depends in a great measure on the couch being properly sprinkled with water. In forming solutions of the metals in the muriatic and some other acids, the water becomes decomposed in proportion as its oxygen is required to oxidize the metal, and its hydrogen escapes through the fluid in the form of gas. This in some degree accounts for the great loss of weight which is always experienced in making the solutions of tin and other metals.

Here it may perhaps not be amiss to advert to a circumstance which may involve the safety of some individuals. What I allude to is this; that those persons who are in the habit of preparing large quantities of muriate of tin, are perpetually liable to misfortunes by an explosion of the hydrogen gas which escapes during the process. Very lately, a friend of mine in the country was much cut in the face and otherwise injured by the fragments of an apparatus in which this operation was going on, and which burst with a tremendous report, in consequence of a lighted candle having been incautiously brought too near it.

Though water is decomposed and a loss of weight is sustained in many chemical operations, water, on the contrary, is often *produced* in certain cases of combustion, where the presence of this fluid is least suspected; and this may influence the results of many operations in a way that is quite inexplicable to those who are unacquainted with the principles of chemistry. Spirits of wine, oils, wax, tallow, and many other substances, always produce water during their combustion. If a cold glass vessel be inverted over the flame of burning alcohol, water may be collected that is perfectly free from taste or smell, and in every respect like distilled water. One pound of alcohol will produce eighteen ounces of water.

The PURITY of the water that is employed in some of our manufactures is an object of the most material consequence. A few instances may easily be adduced to substantiate the truth of this assertion.

In the processes of bleaching, dyeing, and calico-printing; in those of refining sugar, of brewing malt liquors; in the manufacture of paper, and in many others which might be enumerated;

the quality of the article is much influenced by the nature of the water which has been employed in its production.

More than two thousand years ago Hippocrates wrote expressly on the difference observable in waters. Celsus gave directions for examining the specific gravity of water¹, and Pliny attempted to direct his readers how to distinguish the salubrious from that which is unwholesome. But, till the time of Boyle or towards the end of the seventeenth century, no means had been devised of analysing water, or of pronouncing with certainty on its nature and properties.

There is a letter still extant from Synesius, a Christian bishop of the fifth century, to the female philosopher Hypatia, under whom he had formerly studied, in which he complains of being ill; says that he wishes to use a *hydroscopium*, and requests that she would cause one to be constructed for him. "It is a cylindrical tube," he adds, "of the size of a reed or pipe. A line is drawn upon it lengthwise, which is intersected by others, and these point out the weight of water." It is probable that the bishop was in an infirm state, that his physicians had ordered him to drink none but pure water, and that the instrument he wanted was one similar to our hydrometer for the purpose of examining the weight of different waters, in order to ascertain which would be best for his use.

Those which are generally known by the appellation of *hard* waters, hold certain salts in solution, and are unfit for private use as well as for manufacturing processes. Frequently, however, according to the remark of Bergman, the sum of all the saline substances dissolved in a mineral water does not exceed a six-thousandth part of its weight, and yet may be composed of six or eight different substances. Mr. Dalton asserts, from the result of his own experiments, that the hardest spring water seldom contains so much as one-thousandth part of its weight of any foreign body in solution².

Nature, who in her inexhaustible bounty gives us distilled water from heaven, has so ordained it, that there are few districts of much extent where spring water may not also be found, which is sufficiently pure for most purposes either of manufacture or domestic economy³.

It may here be remarked, that in sinking wells it is important to line them with free-stone, and not with bricks as is usual,

¹ Celsus *De Medicina*, lib. ii. cap. 18.

² *New System of Chemical Philosophy*, p. 271.

³ A rare instance to the contrary is mentioned by Dr. Plot in his History of Staffordshire, who relates a case of a well which was sunk in that county to the depth of 2,600 feet, without meeting with water. See *Journ. des Sav.* 1680, p. 14.

because most of the bricks which are made in this country have the property of hardening the water; whereas the stone has not this effect.

Nearly seventy years ago Dr. Home explained why hard water is injurious to dyers and bleachers. It is related by him that Mr. Samuel Hart, who was a celebrated bleacher in the middle of the last century, was about to establish a new bleach-field in a particular place, which seemed favourable for his purpose on account of the appearance of the water and the abundance of the supply; but when he came to examine it by some of the best chemical means then known, it was found so impure, that he deemed it expedient to form his intended establishment on another spot. Most of our spring water contains common salt, with carbonate and muriate of lime; but it is the *sulphate* of lime which constitutes what we call *hard* water.

In coal districts, where the coal occurs near the surface of the ground, the brooks and rivers in the neighbourhood are often contaminated by the result of the decomposition of the sulphuret of iron called martial pyrites, which is washed into them by the rains. I know of one instance in Yorkshire where an establishment for scouring and dyeing woollen yarn must have been entirely broken up from this cause alone, if the proprietors had not found the means of leading a current of water from an adjacent spring for the supply of the manufactory.

They had been in the habit of using the water from the river Calder, which has constantly a portion of the coal-pit water running into it; and in the summer months, or in very dry seasons when there is less good water to dilute the coal-pit stream, the Calder water, for most of the purposes for which a dyer requires it, is rendered nearly useless. This had long been a cause of vexation and inconvenience to these individuals, when the bursting of one of the worn-out coal-pits so inundated the bed of the Calder with the solution of sulphate of iron, that its water became totally unfit for their purpose; and this induced them to resolve upon incurring the expense of supplying themselves from another source. The establishment of which I have been speaking is not a large one, and yet the proprietors have repeatedly assured me that the consumption of soap in scouring their woollen yarn is, in consequence of the softness of the present water, so much diminished as to occasion a saving to them of more than fifty pounds per annum.

To those persons who have no idea that difference of water can produce such important effects in bleaching, I would earnestly recommend the repetition of the following easy experiment. Take half a pint of *distilled* water—drop into it a single drop of the tincture of galls and an equal quantity of solution of sulphate

of iron, and let the whole be stirred with a glass rod. On observing the effect which this minute quantity of these reagents has produced in the water, it will be perceived that only a very slight change of colour has been occasioned by it ; whereas, if an equal quantity of *spring* water be added to the former mixture, the whole will immediately become black.

In some processes of calico-printing the perfection of the water is of great moment, and to the dyer of fine colours pure water is indispensable ; but the case which has just been related refers chiefly to the bleaching of linen and calicoes, which can never take a perfect white if the water employed be contaminated with saline substances or with minerals of a metallic nature. The term *pure* water is not intended to be taken in the strictest sense of the words, for rain water itself is not absolutely pure. Such water, when collected by spouts from the tops of buildings, is found to have dissolved a portion of selenite from the tiles ; and if caught in an open field it is generally contaminated by the heterogeneous particles which are always floating in the atmosphere. For the purposes of chemical analysis nothing can be depended upon but distilled water. The ancient chemists, however, always preferred rain water for all their processes.

In reference to bleaching it may be worth while to mention, that there are many manufacturing districts in this kingdom which are situated near to peat mosses, some of which are of considerable extent ; and that all such places are very improper for the establishment of bleach-works, because at flood time these marshes pour into the adjacent rivers large quantities of iron in a state of solution which contaminate the waters for many miles.

A remarkable instance of the impurity of spring water occurs in Portugal. In several parts of that kingdom the waters are so hard that for many purposes they are entirely useless. The following is a case of peculiar difficulty.

The wool which is produced in Spain and Portugal contains so much animal oil and other impurities, that when scoured it will not produce more than half its original weight, and in some cases three pounds will not yield more than one pound of clean wool fit for the English market. As these wools pay a considerable duty to the Spanish and Portuguese Governments on their exportation, the Spaniard finds it his interest to clean them thoroughly before they are shipped for sale to Britain or elsewhere ; but in Portugal the merchant cannot avail himself of this expedient, because the waters of that country are unfit for the operation.

I know a merchant who has an establishment in Portugal for the purchase of wool and for the sale of English woollen cloth, and he informs me that he is under the necessity of shipping very

large parcels of wool in its original state, which occasions a great reduction of profit, merely for want of the means of having this wool properly washed in Portugal.

I suggested to this gentleman the scheme of collecting urine for the purpose. I stated that this fluid, when it becomes stale, produces a large portion of volatile alkali, and that the addition of a small quantity of quick lime would remove its offensive smell and render it fit for any operation of washing or scouring: and that it would, if added in a small proportion to hard water, render such water soft and fit for any deterative process whatever. But he assured me that this could not be done; for that the inhabitants of this country have so much pride, and so little idea of the importance of manufactures, or of any economical improvements, that it would be impossible, by any reward, to induce the poorest man in the country to engage in such an occupation.

The ancient Romans had recourse to urine for scouring woollen cloths. It is, indeed, probable that it was more largely employed by them for this purpose than even by the moderns, from the circumstance of the Emperor Vespasian having laid a tax upon it, which remained long in force, and continued to be exacted for more than 200 years. The scourers of old were so careful in the collection of this article, that the Government extorted the payment of the tax even from those who kept cattle, *vectigal pro urina jumentorum*. Athanasius, however, although he was the most frugal and economical of all the Roman emperors, relieved his people from this odious impost.—Pliny, lib. xxviii. § 6. &c.

It is probable that the ancients had no conception of the method above mentioned, of sweetening stale urine, because it appears that the scourers at Rome were all obliged to reside in the most unfrequented parts of the city.

It would extend this Essay to too great a length to lay down rules for the complete analysis of all the various kinds of water which these islands produce, especially as Dr. Kirwan and others have written expressly on this branch of the subject: but some directions for ascertaining the *comparative* goodness of water may be of especial service to the manufacturing part of the community, and this may perhaps be done without occupying much room, or occasioning fatigue to the general reader; and it may be observed, as we proceed, that it is of consequence also to the agriculturist to be able, in some measure, to analyse water; for those who have studied the subject of irrigation, and carefully observed its effects, have found that the benefits resulting from this practice very much depend upon the nature of the water which is employed¹.

¹ See Boswell's *Treatise on Watering Meadows*, p. 10, &c.

Even horses will refuse hard water when they have long been accustomed to soft.

In examining water, the first thing to be attended to is its specific gravity; and I conclude, from a remark which is made by Pliny, that this method of trying the purity of water was known to his contemporaries. "Good water," says he, "ought to have neither taste nor odour at all. Some there be who judge of their wholesomeness by the balance, and they keep weighing and poizing of waters one against another¹."

There can be no doubt of the importance of attending to the specific gravity of spring or river water, as this alone will often lead to a knowledge of its nature and purity; for those waters which are the most unfit for culinary purposes, or for the use of manufacturers, are generally specifically heavier in proportion to their impurity. If, therefore, a sample of water should prove to be of the same weight, or but a little heavier than rain or distilled water, and devoid of colour, taste, and smell, it may generally be pronounced to be fit for most purposes, either of the arts or of domestic economy.

Should it be intended to prosecute the examination further, it will be an easy experiment to put a thin slice or two of white soap into a clean glass tumbler, and then to pour half a pint of the water over it, which is required to be examined. When this has stood undisturbed for half an hour, the appearance of the water will be a good evidence of its relative purity, as it will then be seen whether it be what is called *hard*, and consequently impure, water, or otherwise. The Spanish soap, usually known by the name of Castile soap, an article sold by the chemists, and which is made of soda and oil of olives or oil of almonds, is the best; but good English white soap will generally be found very suitable for the purpose. A little Venice soap dissolved in alcohol will form a test by which the comparative hardness of water may be determined in an instant.

Water which holds any of the earths in solution, or any of the metallic or earthy salts, has the property of decomposing soap, while pure water will completely dissolve it. In the former case the alkali separates, and the earth combines with the oil or the tallow; in the latter, the soap is decomposed by double affinity, the acid uniting with the alkali, while the earth or the metal combines with the oil, and forms an earthy or metallic soap. In both instances the new compound is insoluble, which occasions the coagulation above mentioned. It may therefore be said that in this experiment, if the fluid present a smooth equable appearance, without any white flakes or curdly particles interspersed among

¹ Holland's *Pliny*, book xxxi. chap. 3.

it, the water may be considered good; otherwise it must be deemed hard, and this in proportion to the quantity of the white insoluble matter which is perceived in it.

One of the substances most commonly found in water, and the most injurious to manufacturers, is iron. To discover the presence of iron, prussiate of potash, or tincture of galls, may be employed. The first of these reagents will occasion a *blue* colour in the water if iron be present; the tincture of galls will produce at first a purple and then a *black* tinge.

These short directions will be enough to enable manufacturers in general to ascertain whether the water in their vicinity has a degree of purity sufficient for their respective purposes: and wherever a complete analysis is required, recourse must be had to Kirwan², or to some other chemical writer who has given the proper directions for conducting such an examination. In pursuing this inquiry, "Bergman's Physical and Chemical Essays," "Dr. Henry's Elements of Experimental Chemistry," "Dr. Thomson's and Murray's Systems of Chemistry," and the fourth volume of "Fourcroy's General System of Chemical Knowledge," may all be read with advantage.

It may however be worth while to embrace this opportunity of showing that brooks, rivers, and springs, are liable to be contaminated with a variety of impurities, all of which may be detected by chemical reagents in the following order. Other substances however, besides those which are enumerated in the subjoined list, have been found in natural waters; but as these are such as are chiefly to be expected, it has not been thought necessary to enlarge the catalogue.

A tabular View of those Reagents which are usually employed to detect the Impurities of Spring and River Water.

Oxalic acid, or any of the oxalates	} will discover	{ Lime, or either of the salts of lime.
Infusion of litmus, or syrup of violets	}	{ Uncombined acids.
The same slightly reddened by vinegar; or turmeric paper	}	{ Pure alkalies and pure earths.
Muriate of platinum		Potash, or the salts of potash.
Acidulous nitrate of silver		Muriatic acid, or the muriatic salts.
Muriate of barytes		Sulphuric acid, or the sulphuric salts.
Lime water		Carbonic acid, magnesia and alumina.
Acetate of lead		Sulphuretted hydrogen.
Muriate of lime		Carbonated alkalies.
Polished iron or steel		Sulphate of copper.
Phosphate of soda ³		Magnesia.
Sulphuret of potash		Lead.

² See his *Essay on the Analysis of Mineral Waters*, London, 1799.

³ This test for magnesia was first recommended by Dr. Wollaston. For the method of managing it, see Dr. Henry's *Chemistry*, vol. ii, page 431.

The manufacturer having ascertained, by means of one or more of these tests, that the water upon his premises is not fit for his purpose, it then becomes a question of prudence whether he shall attempt to purify this water, or search for some other source from whence he may draw such as is naturally pure enough for the use of his manufactory.

It is probable that in many parts of this kingdom such a search would be crowned with success. Dr. Home has stated that "the water of the Edinburgh wells not only thoroughly dissolves soap, and retains its transparency when salt of tartar is mixed with it, but even shows no lactescency when nitrate of mercury is dropped in."

The means which might be adopted for the purification of water are various, and Nature herself makes use of several of them in order to present us with this article of the first necessity, in a state of sufficient perfection for all the common purposes of life; and among other operations she chiefly employs those of distillation and filtration.

The most contaminated waters on the face of the earth are daily purified by the action of the sun's beams, which separate the limpid particles from the polluted mass, and elevate them into clouds, from whence they are distilled in showers of rain, hail or snow. The hills and mountains of the globe also perform a similar office, by allowing the waters in their vicinity to percolate through them, and hence are presented to us in various degrees of purity, according to the nature of the different strata of earths or minerals through which they have permeated¹.

The former of these methods is successfully imitated whenever we prepare distilled water; but this is a process which is too expensive for most manufacturing purposes. The latter, that of percolation, may be copied by art on a large scale; and the water which is thus purified, may be employed for some uses with considerable advantage. Here, however, we can only strain off some common contingent matters without changing the soluble principles; while Nature, by her superior powers, can even decompose what is injurious, and cause the impurities to subside or separate entirely.

I have often thought that at those large works where a steam-engine is constantly employed, a sufficient quantity of distilled water for all the nicer purposes might be collected from the waste steam, if a proper receptacle were contrived for condensing it. The advantages that would accrue from such an arrangement to the dyer of rich colours, and to the printer of fine calicoes, are incalculable.

¹ Those springs which arise out of lime-stone rocks are generally hard; whereas, the waters which have filtrated through a long extent of gravel are often extremely soft.

Here it may be observed, that when fresh water becomes scarce at sea, excellent soft water may be readily procured for the use of the ship's crew, by distilling the salt water with some wood-ashes or other vegetable alkali. A memoir expressly on this subject may be seen in the Philosophical Transactions for the year 1758.

I had some time since an opportunity of examining the plan of an extensive reservoir, at that time making by a very ingenious manufacturer for the sole purpose of filtrating water, and which was of the enormous size of sixty yards long and forty yards wide. This vast receptacle was formed near the side of a river, and sunk several feet below the surface of the adjacent ground. When the soil had been carried out to a depth which was thought sufficient, several broad trenches were sunk a foot or two deeper than the main bottom, and these were filled with boulder stones or very large pebbles, to prevent the possibility of these passages for the water from ever being filled up. Over these, and over the whole bottom of the reservoir, a large bed of gravel was laid, and then the remainder of the pit was filled up with fine screened sand.

In using this reservoir, it was the intention of the proprietors to fill it with water, by means of a pump fixed within the river and worked by the steam-engine; and it was considered that the water would be purified in its passage, while pervading the sand and gravel; that the trenches below would be constantly full of pure water, and that the manufactory would be furnished with a perpetual and transparent limpid stream.

I have not yet heard of the success of this project, but I have no doubt of its answering fully all the expectations of the projectors; though it must be recollected by those who may be desirous of practising this mode of purification, that it is only capable of separating the argillaceous earth, or such impurities as are merely suspended in the water, and not any of the earths or salts which are chemically combined or dissolved in it.

In making a reservoir of this kind, there are many circumstances to be attended to, which may appear insignificant in themselves, and yet the neglect of one of them may be sufficient to defeat the whole of the intention. Thus, if precautions are not taken, worms will burrow through the bottom and sides of such receptacles, and by the passages thus formed will divert the water from the bed of the filtrating materials into other channels.

To guard against this, it is necessary, when the bed of the reservoir has been well puddled with clay, to lay a thin coat of coal-ashes over it, and to secure the sides in the same manner; it having been found that this will effectually prevent these small animals from penetrating.

It is also necessary, when the gutters are filled with the boulder stones, to cover them with long straw to prevent the gravel from running among them. The same expedient should likewise be adopted afterwards, when all the gravel has been laid on, to prevent the sand which is then to be spread over from running among it; but where a large sum is to be expended in one of these reservoirs, I would earnestly recommend that the advice of a person should be taken who has had experience in these matters.

In pursuing the subject of purifying waters for the use of our respective manufactories, I would remark that it is right to encourage the growth of weeds, and the different kinds of aquatic vegetables, in all large reservoirs of water belonging to such establishments, as they have the faculty of very materially purifying the water in which they grow. Some very interesting dissertations on this subject will be found in Priestley's *Experiments on Air*, p. 16—63, under the article "Green vegetable matter floating on stagnant water." Hard waters have the property of retarding animal and vegetable putrefaction; but when putrefaction does take place in such waters, it alters their quality, and they become entirely soft. The antiseptic quality of hard waters was known to Celsus, an eminent physician of the first century. "If this were the proper place," says Dr. Home, "we could easily account for all the bad effects of hard water on the human body; and show that by the separation of the acid from the terrestrial base, which will happen in the body, several diseases must arise. These unwholesome effects of hard water may be prevented by previously mixing alkaline salts with it." Some waters are purified sufficiently for manufacturing purposes, merely by an exposure to the action of the atmosphere. Thus some chalybeate waters deposit the iron in a thin pellicle on their surface, owing to its becoming insoluble by its absorption of oxygen. I know also of an instance at a print work, where a very shallow stream of water, which ran through the works, was found too impure for many of their purposes: but when the same rivulet had passed these premises, and had reached another work which belonged to the same proprietors, situated at a considerable distance from the former, it was always found to be fit for most of their operations.

A large portion of the spring water of this country is rendered unfit for many manufacturing purposes by the selenite which is contained in it; but surely such water might, at a trifling expense, be sufficiently purified for most occasions, unless the consumption of it were so large, as that this circumstance alone would create an insurmountable objection.

Water contaminated by selenite (sulphate of lime) may be ren-

dered pure by means of a solution of barytes, an article which may be prepared at a comparatively small expense, and would be of incalculable advantage in many processes of art. I have here in view the preparation of barytic earth from the common Derbyshire caulk, as described in Essay 4, and which I conceive would be sufficiently pure for this purpose. All that would be necessary would be to drop the solution of that earth, by degrees, and in small portions, into the water intended to be purified, till it occasions no further precipitate. In this way pure water might at any time be had for chemical experiments; for, if too much of the barytic solution should by accident be employed, the carbonic acid inherent in the water, or that of the atmosphere, will soon combine with it, and occasion it to precipitate along with the decomposed selenite. I cannot however recommend the water purified in this way to be used for domestic purposes, as the barytic earth is poisonous.

When barytes is not to be had, and in all cases where it would be improper to employ that earth, such water may be rendered soft, though not perfectly pure, by the addition of a small quantity of the sub-carbonate of potash (the pearlash of the shops), or a few of the crystals of soda. Either of these alkalies will combine with the sulphuric acid and precipitate the lime; and when a sufficient time has been allowed for the deposit to be formed, such water will be fit for every culinary, and for most manufacturing or domestic purposes. Where there is the convenience of proper reservoirs, this is a most effectual way of softening hard waters; and for every purpose of washing or scouring, the effect may be produced at a still cheaper rate by means of stale urine. This might be sweetened as directed at page 431, and then poured into the water by degrees till the object was completely attained.

The great desideratum, however, with bleachers, dyers, and calico-printers, is to discover a cheap method of precipitating iron from any of those waters in which it may be dissolved, as the salts of iron held in solution by the waters of brooks and rivers are often very injurious in the practice of those arts.

The solvent of the iron in these cases is often, if not generally, sulphuric acid; therefore, in those situations where it is convenient to have cisterns or other reservoirs for the water, the solution of pure barytes might be employed with equal effect. The barytic earth would immediately seize the sulphuric acid and precipitate it; and the iron, having thus lost its solvent, would fall also. This precipitation of these impurities will commence immediately upon the application of the barytes; and when the whole has remained a few hours undisturbed, the water will be fit for use. It will be obvious that care must be taken to add no more of the barytic solution than is absolutely necessary to throw down the iron;

otherwise, when the iron has been separated, the water will be found to be contaminated by the reagent itself. In Scotland the poor get up their own household linen, and bleach it themselves in their own gardens. Dr. Home relates the case of a poor woman who watered some webs she was bleaching, from a spring near her own house. To her great surprise, they became redder and redder every day. She attributed it to witchcraft; imputed the crime to the neighbour she hated most; and sold the cloths for a trifle. The Doctor afterwards analysed the water, and found it contained iron. To discover whether the iron be held in solution by the sulphuric, the muriatic, or the carbonic acid, treat it with a small quantity of the nitrate of barytes. If this throws down a yellow precipitate, and the water loses its brackish taste, it may be concluded that the iron is dissolved by the former of these acids; but if these effects are not produced, some other acid must be considered to be the solvent. Boiling the water will show whether it is carbonic acid that holds it in solution.

In cases where no danger would arise from a small portion of lime, waters may, indeed, be divested of iron merely by the addition of a little of this earth in powder¹. It would be proper to use *fresh burnt* lime; and should more of this be employed than is necessary to separate the iron, the superabundant quantity may be precipitated by allowing it time to absorb carbonic acid from the atmosphere. And where time could not be spared for the completion of this process, the judicious application of a very small quantity of sulphuric acid would separate the whole in the course of twenty-four hours, and leave the mass of water in a state of purity fit for any purpose either of manufacture or domestic economy.

To accomplish this on a large scale it will be necessary to have two reservoirs, which might adjoin each other, and then the impurities would be subsiding in one, and its water becoming fit for use by the time the water of the other was expended.

From repeated observations I am convinced that large sums of money have been needlessly spent in the purchase of expensive cements for making underground water-cisterns, and that brick walls properly built and well puddled with clay are fully sufficient for the purpose. I have myself more than once constructed a large underground cistern in this manner, which held perfectly tight for several years, and probably would last at least a century. A detail of the methods which I pursued would occupy more room than I can spare; but I refer the reader to a work where he may obtain an abundance of useful information on this sub-

¹ Pliny speaks of purifying brackish water with chalk, which is a carbonate of lime. See lib. xxiv. cap. 1.

ject, viz. Switzer's System of Hydrostatics, in 2 vols. quarto, London 1729, vol. i. p. 129, illustrated with a copper-plate engraving of the sections of several reservoirs of different forms and dimensions. Vitruvius says that the ancients constructed their underground cisterns with a composition made of lime-mortar, sand and pebbles, well beaten together.—Vitruv. *de Archit.* lib. viii. cap. 6.

I am acquainted with some gentlemen in the north of Scotland who are proprietors of a very extensive establishment for bleaching and printing calicoes, and who for many years had been in the habit of bleaching with the water from the river Don, but had long been dissatisfied with the uncertainty that attended all their processes, and which they could ascribe to nothing but the impurity of the water.

These gentlemen possessing much chemical knowledge, at length came to the determination of analysing the waters of all the neighbouring springs, and then to bleach a parcel of goods with the utmost care in that which appeared to possess the greatest purity. The result answered their most sanguine expectations. Less alkali was required in the process, and the difference in the appearance of the finished goods was very considerable and obvious.

When the superiority of this spring of water was thus ascertained, the individuals above referred to were at the expense of conducting it in pipes three miles through their own estate, taking care to divert the waters of those springs which contained iron into another channel. The good water was made to empty itself into one vast cistern capable of containing many thousand gallons.

This reservoir, which is formed with large slabs of Scotch granite, put together with Parker's cement, is fifty feet long, thirty feet wide, and ten feet deep.

It is observable that the reservoir is very shallow in comparison with its extent, and this form was given to it in order that a large surface of water should be constantly exposed to the atmosphere. The design of this will be immediately perceived, when it is understood that this water passes through a bed of lime-stone, and that when it is delivered at the reservoir it holds a portion of that earth in solution. For by this exposure of it to the air, it loses that excess of carbonic acid which dissolved the carbonate of lime, and then this earth from its natural insolubility separates, and falls to the bottom of the cistern. Mr. Cavendish determined that 1200 grains of water impregnated with fixed air and yet not fully aerated, could hold in solution one grain of chalk. Berthollet in *Mém. Paris* 1780, p. 127, states, that 500 grains of water *fully* impregnated with fixed air

can hold one grain of aërated lime ; and Kirwan has shown, that when the proportion of water to that of chalk is very considerable, for instance, as 12,000 to one, then the weight of fixed air necessary to keep the lime in solution is about half its weight when aërated ; and if the proportion of water be still more considerable, a still smaller weight of fixed air is required. He also states that if the weight of the carbonic acid which is united to water exceeds that of the chalk, it will dissolve it let its volume with respect to that of the water be ever so small. It having, however, been foreseen that the precipitate of calcareous earth would constantly accumulate in this reservoir, and soon become considerable, the water from the pipe of conveyance is not allowed to rush in at the surface, but is delivered into a capacious wooden trough which goes nearly to the bottom of the cistern. By this contrivance no water can enter but at the bottom, and there it becomes distributed, without occasioning the least disturbance to the surface ; which is a point of considerable consequence, especially as the manufactory is supplied, as will be explained hereafter, only from the uppermost stratum.

At first an inconvenience arose from the circumstance of conveying the water from the spring in *iron* pipes, as those parts which were not constantly covered with water became oxidized by the action of the atmosphere, and in consequence of this the contents of the reservoir were soon contaminated by iron in a considerable degree. However, by adapting a stop-cock, and otherwise preventing the circulation of air within the pipes, the iron is now preserved from solution, and the complaint of having a chalybeate water is no more heard.

It being a main object with the proprietors of this manufactory to improve the water by exposing it to the action of the air, in the way already noted, they conceived that the upper stratum must always be the purest, and therefore they determined never to draw any off for the use either of bleaching or calico printing but from the surface, and this they effect by the following expedient.

A copper pipe, with a large stop-cock attached to it, is firmly fixed in one side of the reservoir, at a convenient distance from the bottom ; and at that end of the pipe which is within the water, a flexible tube of leather about 18 inches long is affixed and supported upon rings of copper, sewed withinside to prevent the pressure of the water from occasioning the leather to collapse. It will be obvious that where the water is not to be consumed close to the reservoir, a series of pipes, instead of the stop-cock, might be attached to the flexible tube, and thus the water might be conveyed to any distance. To the other end of this flexible pipe, one of copper is fixed, with a rose-head, as it is called, at

the other extremity; that is, this end of the pipe is pierced full of small holes for the entrance of the water, and this is surmounted by a large air ball made of thin copper so as to be capable of swimming in water. By this contrivance, whatever depth of water there may be in the reservoir, one half of the air ball is always out of the water, for the flexible tube allows it to rise or fall with the water, and consequently the perforated end of the copper pipe at which the water enters is never more than an inch or two beneath the surface, so that none but the very purest portion of water within the reservoir can ever be drawn off for use.

It appears to me, that this is a very simple and effectual contrivance for obtaining good water; and the improvements which have obviously appeared in several of the processes of this establishment justify my recommendation of the scheme, and induce me to say that it is my decided opinion that a similar one should be adopted not only at other works in Scotland, but throughout the British dominions by all those bleachers or printers whose situations will admit of it.

The necessity there is of pure water for the use of the bleacher has been fully explained in the foregoing Essay; but to the printer of fine calicoes it is, perhaps, of still greater importance. Such water must be used in every process from the first to the last for the *light coloured* prints; for a single operation either of dunging, washing or dyeing such pieces in common water, would spoil the delicacy of the grounds, and decidedly impair the beauty of the goods.

Bleachers are not always aware of the loss they sustain, in the extra consumption of potash, by the use of hard water; nor are they apprised that the saline substances which render the water hard, must either be all neutralized or decomposed at the expense of the alkali, before such water can be rendered efficient in any of their processes. A table of the comparative power of various substances with regard to softening and hardening of water, will be found in the work of Dr. Home already quoted, page 249. Likewise several curious experiments on the effects of different waters in sundry culinary operations, pages 288—298.

Brewers of malt-liquors labour under as great an inconvenience from the use of hard water; for it is well known that the largest portion of extractive matter cannot be drawn or separated from the vegetable substance by means of such water. The annual profit of a brewer must therefore in a great measure depend upon the purity of the water he employs, as well as on the goodness of his malt.

To the grower of flax for the operation of steeping, *soft* water is of the utmost consequence. In such water the process usually goes on with regularity and safety, whereas in water that has a

considerable degree of hardness, the flax may lie month after month until its texture be injured, and still the ligneous matter will not be properly separated. The intention of steeping is to loosen the *harl* or bark of the flax from the *bun* or woody part of the plant; and this is accomplished by a solution of the mucilaginous substance which occasions them to cohere. Putrefaction being the means employed to attain that end, hard water must be improper for steeping, because all such waters have the property of resisting the putrefactive process. Dr. Home, who made many experiments on this particular branch of our subject¹, assures us that flax may lie even four or five months in moss-water before it will be sufficiently steeped. Hence he recommends “that the steeping should be made a business distinct from the raising of flax,” and says that in Holland it is managed by lint-dressers, who buy the flax standing on the ground, and carry it to their own premises to steep. He has also remarked that the flax, when properly watered, acquires a slippery oiliness on its skin, owing to a solution of the mucilage; but Pliny’s rule is still the most certain, “*Maceratos indicio est membrana laxatior*”².

From the experiments which I have myself made in DYEING, I am convinced there are few of the dye-woods or other vegetable substances that are employed in that art, which will yield their colours freely to any but *pure* water. Dr. Bancroft discovered that if logwood be boiled in distilled water, it will give a *yellow* decoction³, whereas we all know that a decoction of this wood when made with common spring water is of a full *red*, or a dark blood-colour.

By the experiments of Dr. Percival it has been ascertained, that soft water acts more powerfully as a menstruum on vegetable bitters and astringents than hard pump water, and that it dissolves some resinous bodies without any medium, or at least with a much smaller proportion of mucilage than is commonly employed⁴.

The baneful effects of impure water on the human constitution have been already noticed in a former part of this Essay; and I am now desirous of impressing upon my readers the importance of their examining the nature of the water they drink, and of advising them, should it be impure, to adopt some of the means already recommended for obtaining it in a state of greater perfection. Herodotus relates, that in Ethiopia the inhabitants live to

¹ See his *Treatise on Bleaching*, page 318.

² Plinii *Hist. Nat.* lib. xix.

³ Bancroft’s *Philosophy of permanent Colours*, vol. ii. p. 341.

⁴ *Experiments and Observations on the Pump Water of Manchester*, by Dr. Percival, octavo, London 1769.

be an hundred and twenty years old; that they eat animal food and drink the water of their own country, which is so light that wood will not swim upon it, and that it is the use of this water that prolongs their lives⁵. Dr. Percival says that the Spaniards are entirely exempt from many of our cutaneous diseases; and the reason he assigns for this remarkable fact is, that the air of Spain is clear and serene, and the water they drink pure and wholesome.

In the water of the Pei-ho river in China, the mud is suspended in such large quantities as to render it scarcely potable. This water is, however, quickly refined for use by the following simple process. A small lump of alum is put into the hollow joint of a bamboo, which is perforated with several holes. The water taken from the river is stirred about with this bamboo for three or four minutes, during which the earthy particles uniting with the alum are precipitated to the bottom, leaving the water above them pure and clear. Persons of rank in China are so careful about the quality of the water intended for their own consumption, that they seldom drink any but what has been distilled⁶.

It was formerly a general complaint that the health of maritime people was much injured by the internal use of water which had become in some degree putrid by age, or in other words by being kept stagnant for so long a period as is sometimes necessary on long voyages. In modern times, however, various expedients have been contrived to obviate this great inconvenience. Dr. Stephen Hales discovered that good wholesome water may be procured on a voyage by the distillation of sea water, if $\frac{1}{4}$ lb of chalk be previously mixed with every gallon of water put into the still. A remarkable circumstance respecting the obtaining of fresh water at sea by those who may be so unfortunate as to have their ship frozen up in the ice all winter, is related by Mr. Boyle. "An old sea captain," he says, "assured him, that when his ship was immured with ice in the frigid zone, so that they could not in a long time get so much as a barrel of salt water, he made wells of the thick pieces of ice, to receive the liquor of the thawed ice, and found this water (though on the main sea) to be good fresh water fit for drinking, for dressing their meat, and other uses, and that he never feared the want of fresh water in those seas."

I am happy to embrace this opportunity of suggesting to those who may have to supply large vessels with stores, that it is always advisable to make choice of *hard* water for the use of the ship's crew, as this resists putrefaction, and consequently will keep good

⁵ Herodotus, lib. iii. cap. 125.

⁶ Macartney's *Embassy to China*, by Sir George Staunton, Bart. 2 vols. quarto, London, 1797, vol. ii. page 68.

much longer than *soft* water. The inconvenience of having none but hard water to use for the different culinary and domestic purposes, and the danger resulting from the continued drinking of such water, can be easily obviated by the use of an alkali, which might be employed occasionally to precipitate the impurities, and on such quantities only as would be required for the wants of those on board, as before directed at page 437.

Such ships as are fitted out from the port of London usually take in their supply of water from the Thames, as this water is said to possess properties which render it peculiarly fit for sustaining a long sea-voyage. At first, after being kept for some time it turns in some degree putrid and offensive, probably from some kind of fermentation; after which it again becomes pure and palatable, so as to serve better than all others for sea-stock. Although the question is of great consequence, I have never yet heard any rational explanation of this phenomenon. "Water taken from the New River in London," says a writer in the *Philosophical Transactions*, No. 127, page 652, "stank very much after being kept stagnant for eight days, but when it arrived at Virginia it again became sweet." The water of the Rhone, if it be suffered to stand for the impurities to subside, and then be put into *earthen* vessels, will not putrefy by heat, though it will soon become fetid if put into *wooden* ones. *Act. Lips.* 1683.

Dr. Priestley, in his *Observations on Air*, vol. ii. p. 185, relates, on the testimony of Mr. Garrick, that the reservoirs for water in the town of Harwich are generally very foul on their sides and at the bottom; and that provided these are not cleansed of what adheres to them, they always preserve the water sweet, otherwise it will become fetid and unfit for use, and the vessel will not recover its sweetness till the sides and bottom grow very foul again. Dr. Priestley supposes, that what they call impurities is merely vegetating matter that adheres to the sides of the vessel, and imbibes every thing tending to putrefaction. May not the change which is effected in the Thames water be attributed to a similar cause?

A curious fact has indeed been recorded by Dr. Boerhaave respecting the preservation of water in a wholesome state under the equator and between the tropics, where stagnant waters always breed an innumerable quantity of insects, and soon become extremely putrid. Water, he says, which has thus spontaneously grown offensive, may be easily rendered wholesome again, and this merely by occasioning it to boil for a moment; for this operation will destroy the animalcula, which, with the rest of the impurities, will subside, and then the addition of a very small quantity of any strong acid, particularly the sulphuric, will render it fit for use. Or if a small portion of sulphuric acid be put to the

water at the first, this will preserve it from animalcula or from putrefying¹.

I must not however suffer this part of the subject to pass over without inserting a caution respecting the use of *leaden* reservoirs and pumps of lead, for the preservation and conveyance of water designed for drinking, because I have reason to believe that this practice has been attended with many very fatal consequences.

The poisonous nature of lead when taken into the stomach in a state of solution is now pretty generally known; but as lead when immersed in water is not soluble in that fluid, persons are apt to imagine that no noxious effects can arise from the use of leaden pipes and cisterns. But, though pure water of itself will neither dissolve nor oxidize this metal, yet the oxygen of the atmosphere combined with the action of the water will convert it to an oxide, when it absorbs carbonic acid gas with avidity from the air, and this renders it capable of solution. The oxides of lead are insoluble in water, but a small portion of any acid, even one of the weakest kind (carbonic acid), will render them soluble. So small a portion as 16 parts of carbonic acid is sufficient to acidify 83 parts of oxide of lead, the whole of which then becomes soluble in water, impregnated with carbonic acid.

The white line which may be seen at the surface of the water in leaden cisterns, is occasioned by the oxidizement of the metal; and as this oxide absorbs the carbonic acid of the atmosphere, the oxide of lead becomes converted to carbonate of lead, and is taken into the stomach of those who drink the water which has been standing in such receptacles. Dr. Percival, Dr. Johnstone, Sir G. Baker, Dr. Lambe, and other physicians, have related many deplorable instances of individuals and even whole families being taken off by this insidious poison. I have myself reason to believe that some years ago I lost an amiable and highly valued relative in this way, and therefore am desirous of inserting an account of these facts, in the hope of recalling the attention of the public to the state of their reservoirs for water, and thus being the humble means of prolonging, if not of saving, the lives of many individuals.

It is necessary, however, to offer a few remarks on some of the properties peculiar to water, and on the various applications of this important fluid. The more obvious properties of water have been mentioned in the early part of this paper, but there are several others to which it is also necessary to advert.

The different appearances and forms which water is capable of assuming have already been slightly noticed. Some further particulars, however, deserve our attention.—In the state of elastic

¹ Dallowe's *Translation of Boerhaave*, vol. i. page 348.

vapour it is perfectly transparent, or invisible to the eye. In this condition it is completely soluble in atmospheric air; and though it may by increase of temperature be attenuated in so remarkable a degree, yet caloric, or the matter of heat necessary to convert it into vapour, is incapable of occasioning any permanent change or alteration in the chemical nature of this fluid.

Atmospheric air and water act reciprocally on each other. The former dissolves aqueous vapour, and water dissolves or absorbs atmospheric air. In its natural state, water is generally esteemed to be 850 times heavier than atmospheric air; but waters differ a little in their specific gravity. I found that a bottle which would hold only 4258 grains of distilled water at the temperature of 60° would contain 4260 grains of New River water, or 4262 grains of pump water such as rises in Goswell Street, London.

Christopher Clavius, the eminent German mathematician, poured some water into a bolt-head, and then sealed the mouth of its neck hermetically, and marked with a diamond the place to which the water rose at that time: he then hung it up, and eighty years afterwards it was found in Kircher's study, just as full as it was at first.—Dallowe's *Boerhaave*, vol. i. p. 326.

The great fluidity of water is one of its most remarkable properties. This property has furnished Shakespeare with one of his beautiful similes:

“ Men's evil manners live in brass, their virtues
We write in water.”

It is this which renders it so useful in many of the mechanical arts, some of which I shall particularize hereafter; and it is owing to this that it has always a tendency to find its own level. Hence it has for many ages been employed to determine the plane of the horizon, and for other philosophical purposes. The solvent power of water is increased by removing the atmospheric pressure from its surface.

The experiment with the solution of sulphate of soda, related at page 424 of this Essay, though introduced for another purpose, is sufficient to prove this fact also; for the water holds all the salt in solution, no longer than the bottle is closely corked; and as soon as the action of the atmosphere is restored, part of the salt precipitates in a crystalline form. Hence, I conceive it to be extremely desirable to try whether some important effects in the art of dyeing, or rather in the processes of extracting the colouring matter of vegetable substances, by means of water, might not be produced by conducting those operations in a partial vacuum.

Another circumstance respecting water is, that its specific gravity is lessened, except in particular cases, by increase of temperature. This fluid might consequently be expected to increase

in its specific gravity in exact ratio with its reduction of temperature; and this is found by experiment to be actually the case, till it be reduced to 42° of Fahrenheit; but after that it becomes specifically lighter by every further abstraction of caloric, and furnishes a memorable instance of one of those deviations from the usual course of nature which its omniscient and beneficent Author has appointed for the preservation of the world, and the welfare and felicity of its inhabitants. I need not, however, particularize, because the fact has already been sufficiently explained in the second of these Essays.

In a variety of chemical operations it is important to know the specific gravity of the water employed. A Table of its specific gravity from 30° to 80° Fahrenheit will be found in the 1st volume of Mr. Brande's Manual, where it is accompanied by an example of its use in reducing the weight or bulk of water employed in any case, to that which it would have at any other common temperature. The solvent power of water is generally influenced by its specific gravity.

Having, in the foregoing paragraph, adverted to the solvent power of water, that circumstance has reminded me of a Table of the solution of salts which I constructed some time ago for my own use. This Table has been extremely serviceable in my own laboratory: I shall therefore insert it, in the hope that it may be of some use to many of those persons who may take the trouble of perusing this volume. I cannot vouch for its perfect accuracy, in every instance, as some of the experiments are difficult to accomplish; but I believe it will be found to be sufficiently correct for every purpose of real business.

A New Table of the Quantity of Water required to dissolve 100 Pounds of each of the following Salts.

Salts.	At 60° .	Boil- ing.	Salts.	At 60° .	Boil- ing.
Sulphate of Magnesia . . .	100	75	Muriate of Magnesia . . .	100	
Ammonia . . .	200	190	Soda . . .	286	280
Potash . . .	1670	500	Potash . . .	300	
super . . .	200	100	Ammonia . . .	340	100
Soda . . .	500	224	Barytes . . .	560	
Alumina and } . . .	2000	133	Phosphate of Ammonia . . .	400	180
Potash . . .			Soda . . .	400	200
Nitrate of Lime . . .	25	20	Chlorate of Potash . . .	2000	304
Magnesia . . .	100		Borax . . .	1180	590
Ammonia . . .	200	50	Carbonate, sub, Ammon. . .	200	100
Soda . . .	300	100	super, ditto . . .		
Potash . . .	720	50	sub, Soda . . .	200	100
Strontites . . .	500		super, ditto . . .		
Barytes . . .	1120	335	sub, Potash . . .		
Muriate of Lime . . .	50		super, ditto . . .	400	125
Strontites . . .	84				

It appears, however, that the contraction and expansion of water by change of temperature were well known to the early chemists. Bacon and Boyle¹ have both written expressly on the subject; but I know of no author (except Sir Charles Blagden and Mr. John Dalton) who has made any direct experiments to determine what kind of ratio is observed by this fluid, in its variation of bulk by the addition or abstraction of caloric. It having occurred to me that a Table of the Expansion and Contraction of Water might be formed which would be very useful to our manufacturers and other practical men, I undertook, some time ago, a series of experiments for that purpose, and the following Table was the result. The specific gravity-bottle and scales which were chosen on this occasion, are described in page 228, and are the same as were employed in making the Sulphuric Acid Tables which are printed in the 7th Essay.

A New Table of the Expansion and Contraction of Water by Change of Temperature. (The Barometer at $29\frac{1}{2}$ Inches.)

Temp. ac. to Fahren- heit.	Contents in grains of a bottle holding 4265 grains of pure water at 42°.	Temp. ac. to Fahren- heit.	Contents in grains of a bottle holding 4265 grains of pure water at 42°.	Temp. ac. to Fahren- heit.	Contents in grains of a bottle holding 4265 grains of pure water at 42°.
32°	4260	64°	4257	120°	4220
34	4261	68	4256	126	4214
36	4262	70	4255	134	4208
38	4263	74	4254	140	4199
40	4264	80	4252	146	4191
42	4265	84	4249	150	4185
44	4264	88	4245	154	4180
46	4263	92	4240	162	4172
48	4262	96	4237	170	4160
50	4261	100	4234	178	4150
52	4260	102	4232	184	4142
56	4259	108	4228	192	4130
60	4258	112	4226	200	4116

Flattering myself that this Table may be of very essential use in many cases of real business, I am desirous of giving an example of its application before I pass on to any other branch of the subject. Suppose a boiler, or other vessel of capacity, to hold 4260 pints, or $532\frac{1}{2}$ gallons of water at any temperature on the range of Fahrenheit's scale between 32 and 52 degrees,—by looking at the figures opposite to 150 in the second column of temperature, it will be seen that such boiler would contain only 4185 pints, or little more than 523 gallons, if heated to that degree; and on looking at the last line, it will appear that such vessel would hold only 4116 pints, or $514\frac{1}{2}$ gallons, at 200°: therefore, should a boiler

¹ *Experimental History of Cold*, by the Honourable Robert Boyle; quarto, London 1683, pages 92 and 113.

be completely filled by $532\frac{1}{2}$ gallons of water of the temperature of 52° , no less than 18 gallons of it would flow over the sides of the vessel before the remainder could be heated to 200° . The maximum of the density of water is at about 42° : this fluid therefore becomes of less specific gravity, whether it be heated above or cooled below that point. This accounts for the seeming anomaly in the table, by which it appears that water occupies the same room at 32° as it does at 52° .

There are some phenomena of water which seem inexplicable, though the authorities I have for them cannot be disputed.

If water be thrown into a crucible of melted glass in a high state of incandescence in a glass-house furnace, the globules of water will dance upon the surface of the melted glass for a considerable time, like so many globules of mercury upon a rum-head; but if a small quantity, or even a pint, of water were to be thrown into such a crucible before the glass is completely fused and while the sandiver is upon its surface, the water would be rarefied into steam in an instant, an explosion would be the consequence, and the furnace would probably be blown into pieces.

In like manner does water sooner evaporate from a plate of iron that is heated to a red-heat only, than from one that has been brought to a welding heat, or nearly to the point of fusion.

Again, in the manufacture of black bottles it frequently happens, while the workmen are engaged in moulding and blowing the bottles, that the metal becomes more cooled than they could desire, so that they find it necessary to give directions to their attendants to throw in more coal and increase the fire. This, however carefully it may be done, will sometimes produce so much dust that the surface of the glass becomes covered with carbonaceous matter. Whenever this occurs, it occasions such a motion within the crucible, that the metal appears as though it were actually boiling; and if it were to be used in this state, every bottle would be speckled throughout and full of air bubbles. But as it would be very inconvenient to wait for the whole of this carbonaceous matter to be consumed by combustion, and as, by being partly mixed with the glass itself, it might occasion it to boil over the sides of the crucible, it was thought very desirable to discover an easy and *immediate* remedy for the accident, and this has been found in common water.

Whenever the accident occurs, the workman throws a little water into each crucible; and this has the effect, not only of stilling the mass immediately, but it renders the metal as smooth and pure as before. This curious and almost instantaneous effect is probably owing to the water becoming decomposed, and affording its oxygen to the coal-dust, and converting it to carbonic

acid gas, which immediately escapes and is dissipated in the atmosphere.

Nothing now remains but to describe some of the various uses to which water has been applied, in different parts of the world, a knowledge of which I conceive may be turned to advantage by some classes of readers.

In enumerating the several purposes to which water has been applied in all ages and countries, I shall slightly pass over the account of the musical instruments of antiquity which were made to play various tunes by means of the pressure of water; and shall also decline any lengthened detail of the methods which were formerly adopted by superstition for the trial of supposed delinquents, by the immersion of the unhappy individuals in water, as these are matters more of curiosity than utility and improvement.

Andrew Brice, in describing one of the palaces of the Grand Duke of Florence, says, "The pilasters are adorned with an organ, which by means of water plays several tunes;" and in a note states, that such hydraulic organs are to be seen in several grottos in Italy.—Brice's *Geog. Dict.* vol. i. p. 574. The invention, however, is not modern; for Cresibus of Alexandria, who lived in the reign of Ptolemy Euergetes, is said to have contrived them. Archimedes and Vitruvius have left descriptions of the instrument, and we find the figure of one on the reverse of a large medallion of Valentinian.

It was formerly a custom in several countries to weigh those that were suspected of magic, it being generally imagined that sorcerers were specifically lighter than other men. This was the origin of the practice of throwing the accused person into water; when, if his body floated upon the surface, he was convicted of witchcraft and burnt, but if it sunk to the bottom he was acquitted. M. Ameillon has published a curious paper in the 37th volume of the Memoirs of the Royal Academy, on this particular subject, in which he endeavours to show the probability that some of these miserable persons did actually float on the water. He states that among the multitude of persons subject to hysteria and other similar complaints there are several who *cannot* sink in the water; and hence he concludes that the pretended magicians and sorcerers who floated when tried by the *water-ordeal*, were persons deeply affected with nervous disorders. Pomme, the celebrated French physician, in his *Traité des Affections Vapoureuses*, supports the same opinion.

Water may be employed as a mechanical power in some of our large manufacturing concerns with great advantage. In the 448th Number of the Philosophical Transactions, page 231, there is a description of a very ingenious water-bellows, invented by Mr.

Triewald, for the use of iron forges and other furnaces, where a great heat is to be produced by forcing a large quantity of atmospheric air into the fire-place. Since the publication of that account, water-bellows upon different constructions have been employed in various parts of this kingdom, for the business already mentioned, and also by those makers of utensils in iron called iron-founders; but the power which may be thus given by water is so great, and the principle is in itself so simple, that I cannot help wishing it were more universally known; for I am confident that it might be brought into greater practice, and extended to a multiplicity of arts and manufactures to which it has not yet been applied. It is not possible, however, to give the reader an accurate idea of this curious mechanical contrivance without a drawing; I must therefore refer him to the copper-plate engraving which accompanies the account of it in the number of the Philosophical Transactions above mentioned.

Bellows moved by water have been long in use at the iron forges in Sweden; and water-bellows on a different construction, and which are employed at Tivoli in Italy, are described in one of the early volumes of the Philosophical Transactions; but those by Mr. Triewald are more simple and on a better principle.

In some particular situations, water is very profitably employed in drawing coals and other minerals from the bowels of the earth. Thirty years ago I recollect having been much gratified in viewing an apparatus of this kind which was then at work in the coal district of Derbyshire, I think somewhere near Ilam; it may be thus described:

Two wooden vessels, or buckets hooped with iron, are fastened one at each end of a very thick hempen rope, and this rope is made to pass over a large wheel which is fixed exactly perpendicular to the mouth of the shaft of the mine. In the commencement of the operation, one of these empty buckets is first lowered to the bottom of the pit, and when it is filled with coals, a boy who is stationed above, and close to the mouth of the pit, lowers the end of a leathern pipe which he holds in his hand, and this immediately fills the upper bucket with water. This being now heavier than the loaded bucket below, it begins to descend with considerable velocity into the mine, while the other ascends with equal speed, and soon arrives at the surface, charged with the coal or other mineral designed to be raised. When the bucket of water reaches the bottom of the pit, it is interrupted by a strong iron pin placed vertically in the ground, exactly in the centre of the spot where the bucket must rest; and this pin forces up a large valve in the bottom of that receptacle, allowing the whole mass of water to escape in an instant. The vessel which has arrived at the top of the pit being emptied, this is now, in its turn,

filled with water, while the men below are loading the other with the mineral, which is then to be raised by the power of the descending water, as before; the buckets continuing to ascend and descend in rotation and without interruption. The specific gravity of water being only a trifle greater than that of a mass of loose coal, this circumstance renders water peculiarly fit for the use of a colliery in the manner above described.

It is obvious however that this contrivance cannot be adopted every where; but I am persuaded there are many places in this kingdom where minerals are raised at a very great expense, though their situations are in every respect favourable for the employment of this machine; and it is this consideration which made me desirous of explaining the scheme in this Essay.

Mines are, moreover, frequently opened on the side of a hill or mountain; and as springs of water are generally to be found in those situations, this method might be employed in all such places, provided there be either a rivulet at the bottom of the mine, or that a fissure in the rock can be found, to carry off the descending water.

I had forgotten to remark, that in providing a stream for setting this apparatus in motion, all that is needful is, to fix a wooden spout into the side of a pool or other contiguous reservoir of water, exactly even with the surface of the water, and then to adapt a flexible tube of leather or other suitable material to that end of the trough which comes to the mouth of the mine. In considering this arrangement, it will be seen that the mere elevation of the leathern end of the pipe a few inches only, will entirely prevent the running of the water; the machine therefore may be kept in motion at any time by a child; and when it is not at work, all that is required is to hang the end of the pipe upon a hook fixed in a post at the side of the pit, when the current will instantly cease.

I might here attempt to describe the various methods of raising water from great depths; but as this would lengthen the Essay more than would be desirable, I must refer the inquiring reader to Nicholson's quarto *Journal of Natural Philosophy*, vol. iv. p. 16-5466, where he will find several elaborate memoirs on that subject, accompanied with plans and engravings.

The fertility of Egypt in consequence of the annual inundation of the Nile, is a matter of general notoriety; and many of the well informed agriculturists of these kingdoms, availing themselves of the knowledge of this fact, do periodically supply their estates with artificial currents of water, and derive great benefit from the practice.

The Chinese have long known how to value the practice of watering land artificially. "I observed," says Van Braam, "several mills which raise the water of the river above the banks,

whence it runs into reservoirs, to be afterwards diffused, by means of canals and aqueducts, over the fields that require irrigation. These mills are of simple construction, and entirely composed of an assemblage of thin bamboos, except the axle-tree of the wheel, which is of timber. In no part is the smallest piece of iron or any other metal employed. The whole machine, as well as I was able to judge, is from 18 to 28 feet in diameter ¹. Being myself one of those who have never entertained a fear of the state being injured by the land becoming too productive, and recollecting that it was said of old, that he deserved well of his country who could make two blades of grass to grow where only one grew before, it is incumbent on me to recommend, in the most forcible terms, the practice of irrigation, and to urge its general adoption.

Mr. Boswell, who has written an elaborate treatise on this subject, says, "It is inconceivable what twenty-four hours water properly conveyed over the land will do in a dry season; a beautiful verdure will arise in a few days, where a parched, rusty soil could only be seen; and one acre will then be found to maintain more stock than ten acres without such management. Moreover, almost the whole of the expense in this mode of cultivation, is the actual manual labour of a class of people who can be employed in no other way for the support of their families; consequently the expenses can be comparatively but small, though the improvement must be great and durable².

It is related of Mons. Pestre, a skilful physician and an enlightened cultivator of land among the Cevennes mountains, that at the first threatenings of a storm he used to clothe himself in a long garment of oil cloth, with an enormous hat of tinned iron firmly fixed by means of straps. Thus defended, he hastened into the midst of his possessions, where alone, with a mattock in his hand, he directed the water to the feet of his trees, and collected the surplus in cavities which he had formed in the rock itself. By these exertions he constantly prevented injurious inundations on his estate, and procured water for his ground at such times when the burning heats rendered it necessary. His neighbours, who, as usual in such cases, at first derided him, were constrained to admire his industry and envy his gains; for, in consequence of this labour, he quadrupled the usual product of his grounds.

Another equally striking proof of the influence of water on

¹ Van Braam's *Embassy to the Court of the Emperor of China*, London 1798, vol. i. p. 72.

² Boswell's *Treatise on Watering Meadows*, illustrated with five copper-plates. Third edition, octavo, London, 1792, p. 12.

vegetation may be found in the very remarkable industry of the gardeners who cultivate the marshes near Paris. From these marshes, situate all around that great city, they derive large profits; they cover the ground with abundant and uninterrupted crops, and they are indebted for this almost astonishing series of vegetable production to the enormous quantity of water, which they are incessantly conveying into their grounds, and to the continual waterings with which they fertilize them.

We read of a very extraordinary stream of water that supplies the public baths of St. Philip, in Tuscany, which carries a peculiar kind of earth, or earthy salt, in its current. This earth, when it is collected and condensed in the cavities of any body that is employed to oppose its course, acquires the nature, hardness, and colour of alabaster, and assumes the forms of the cavities in which it is thus collected. The ingenious Mr. Latapie, convinced by repeated experiments of this singular property of the water of these baths, had moulds made of several single figures, and even groups; and, by placing them in a certain manner against the current of this stream, he collected in their cavities the earth in question, and thus formed *basso relievos* of beautiful alabaster. This success enabled him at length to establish a manufacture, which has rendered the finest productions of sculpture more easily attainable in that part of the country than they had hitherto been, and much more precious by the accuracy of the copy¹.

But it would be an endless attempt to endeavour to enumerate all the various kinds of water which have been noticed by the respective writers who have given us accounts of their travels into different parts of the world. I therefore conclude with the more pleasing task of inviting the contemplative reader to devote a moment or two to the recollection of a few of the more obvious advantages which we derive in every quarter of the globe from the possession of water.

Water is indispensable as the beverage of man and other animals; as the medium for conveying nourishment to vegetables; and for rendering effective those important senses of sight, taste, and smell. It has been well remarked, that that most wonderful machine the *eye* can only represent objects to our senses by the means of humours composed chiefly of water; and that the glassy coats of this important organ must lose their transparency, were they not constantly moistened with water.

I am supported in this assertion by the testimony of an anatomist of great credit and respectability. "Because," says he, "the

¹ For an account of this singular manufactory see *Rozier's Journal* for June 1776; or the *Monthly Review* for November 1776, p. 391.

outermost coat of the eye might be pricked, and this humour let out, therefore nature hath made provision to repair it by the help of certain *water-pipes*, or lymphæducts, inserted into the bulb of the eye, proceeding from glandules that separate this water from the blood².”

In like manner with regard to *smell*, the respective odours of bodies are collected, blended, perfected, and preserved, by means of water; nor could they be conveyed to the proper nerves had not nature supplied these parts with humidity, at once to lubricate the vessels, and to collect the odoriferous exhalation. “The use of this *pituïta*,” says Mr. Cooper, “is to keep the membrane soft. By this means the olfactory nerves expanded on this membrane, are rendered capable of the perception of odoriferous effluvia, which otherwise the *dryness* of the part would destroy³.” Neither is any body *sapid*, unless it either contain water or be dissolvable therein; for it is well known that those substances which are most soluble in water, soonest imprint the sense of taste upon the organs which are destined to receive that impression: a dry tongue can no more taste than dry nostrils smell, or a dry eye distinctly see⁴.

The most beautiful tints of flowers would also be unable to please us if they were divested of water; nor would any of the products of the vegetable kingdom be capable of fermentation, were it not for the intervention of this important fluid. Clay would be mere useless dust without water, and incapable of being modelled into any of the beautiful forms in which we now see it, or applied to any of its present important uses. Lime and sand might be mixed and blended for ever without their forming a compact mass; but by the addition of water they acquire the property of hardening, and of forming for us excellent cements and durable habitations.

Almost all chemical operations require the presence of water, and many others cannot be conducted to any advantage without its assistance. The most powerful and heterogeneous salts, if perfectly dry, may be mixed without any seeming effect; and few if any decompositions could be produced without the agency of this all-pervading and important fluid. The processes of decoction, solution, distillation, precipitation and crystallization, are all dependent upon water for their success. Starch, glue, and every other kind of mucilage, owe their tenacity to water; and it is probable that most of the substances on the face of the earth would

² Ray's *Physico-Theological Discourses*.

³ Mr. William Cooper's *Dissertation on the Smell*, published in Drake's *Anatomy*, vol. ii. London, Third Edition, page 313.

⁴ See Dr. C. Lucas on *Water*, 8vo, London 1756, p. 79.

fall into shapeless or pulverulent masses, useless and inert, were it not for the binding effects of this most accommodating and wonderful fluid.

There are also various reasons for believing that the salubrity of the atmosphere is preserved by means of water; and we are surely not a little indebted to the Great original Contriver of all things for that immense accumulation of this fluid which is collected in the ocean, by means of which we are enabled, without labour or fatigue, to visit every clime on the surface of our globe; to barter the valuable products of each with one another; and to interchange all the important blessings of religion, literature, science, civilization, and the arts.

ESSAY XIV.

ON SAL-AMMONIAC.

SAL-AMMONIAC, or Muriate of Ammonia, is a peculiar neutral salt, well known to the ancients. From the name which this production has always borne, it is extremely probable that it was first collected at Ammonia, a country which occupies the midland part of Libya in Africa, closely bordering on Egypt.

The ancient Temple of Jupiter Ammon was also situated in the country above mentioned, and the proprietors of the stables for the reception of the camels of the pilgrims had contrivances for preserving the urine of these animals for the manufacture of sal-ammoniac¹. In consequence of this, the traffic in muriate of ammonia became very considerable, and the ancient Greeks and Romans, who employed this singular salt for many purposes, procured their supply from that quarter. In process of time, the native Egyptians also learnt how to make sal-ammoniac, and for many ages the whole of Europe had no means of obtaining this salt, except by importing it from that country.

According to Pococke and Niebuhr, manufactories in later times were erected for the express purpose of making this saline compound, at Djise, at Geeza, and at Rosetta a sea-port on the coast of Alexandria, as it was found impossible for the whole of Europe to be supplied from the original manufactory.

In the year 1716 Geoffroy, a celebrated chemist and physician of Paris, read to the Academy a memoir on the composition of muriate of ammonia, and gave it as his opinion that it came from Egypt and was the product of sublimation. In the year 1720 he published an account of a series of experiments, to prove that sal-ammoniac might be made profitably in Europe.

Little was known however of the methods by which this salt was procured in Egypt, until the year 1719, when Lemere, the French Consul at Grand Cairo, sent an account of its manufacture to the Academy of Sciences at Paris, who published it in one of the volumes of their Transactions. I suspect this French Consul to have been a different person from Nicholas Lemery, the ce-

¹ Pliny, lib. xxxi. cap. 7.

lebrated chemist of Rouen, who I believe died early in the eighteenth century. He might perhaps have been a son of the aforementioned Nicholas, for he was also an eminent chemist and likewise physician to the French king. The following is however an abridged detail of the process, as given by Lemere.

The natives of Egypt (says he) collect for this purpose the excrements of camels, oxen, and other animals which feed on saline plants. These excrements are dried by applying them to the surface of walls; and when they are sufficiently dry, they are burned as fuel in their common household fires. It is from the soot afforded by these burning substances that the muriate of ammonia is extracted. For this purpose the soot is put into large glass bottles 18 or 19 inches in diameter, terminating in a neck several inches high. These glasses are filled to within four fingers breadth of the neck, and gradually heated for 72 hours. Towards the second day the muriate of ammonia sublimes and adheres to the upper part of the bottles. When the process is finished and the whole apparatus has been well cooled, the vessels are broken, and the lumps of ammoniacal salt are taken out for sale¹. Five pounds of the soot procured from the burning of this excrementitious matter are expected to produce one pound of muriate of ammonia.

Here it may be worth observing that the soot of Newcastle coals will produce an abundance of sal-ammoniac. Some few years ago there was a considerable manufactory of this salt in the neighbourhood of London, which was supplied entirely by the common soot collected from the chimneys in the metropolis.

Respecting the African sal-ammoniac, other writers relate, that as sea salt is always given copiously to the camels, during their journeys in the caravans over the Desert to Alexandria, their urine and dung consequently become very replete with the salt. The dung of these animals being burnt in the public ovens for hatching chickens for the caravans, and also in their common fires for culinary purposes, the volatile salt is produced in the soot, and this requires only to be purified by sublimation, in order to form the cakes of muriate of ammonia which are exported to Europe.

Chaptal relates, that he obtained sal-ammoniac from the *soot* of cow-dung and that of horses, which run wild in the immense plains of Camargue and Crau, and upon the borders in the numerous marshes in the vicinity of the Mediterranean, but that he soon found he could only procure it from the dung of these animals while they continued to live on *marine* plants.

Another account of the Egyptian manufacture may be seen in Hasselquist's Travels in the Levant. It differs in some respects

¹ Fourcroy's *System of Chemistry*, vol. iii. p. 275.

from the foregoing, but it is extremely interesting. He relates that the poor inhabitants of Egypt are occupied for several months of the year in collecting the excrementitious products already spoken of; that they mix these with cut straw to assist its drying; that when dried they use it as fuel, having in reality no other kind; and that they make a business of collecting the soot from all parts of the country to sell to the sal-ammoniac makers at Grand Cairo.

When the origin of this volatile salt had thus been made known, it was soon discovered that it was a compound body; that it existed ready formed in some parts of the earth; and that it consisted of a peculiar alkaline substance, in close union with muriatic acid.

The acid which was found to be one of its component parts had been known for a century before, and employed for a variety of purposes; but this was not the case with its base, the ammonia, or volatile alkali, which engaged the attention of chemists for many years afterwards, and long before its nature and properties were at all understood, or that it had been even suspected to be any thing more than a simple undecomposable body.

Tournefort was the first chemist who asserted that sal-ammoniac is composed of muriatic acid and ammonia: he made this known in the year 1700. Muriate of ammonia is sometimes found in the environs of volcanoes, and in a state of solution in some lakes in Italy and Tuscany². It exists also in the mountains of Tartary, in Thibet, and in the grottos in the vicinity of Pouzzola³. This salt is likewise found in the country of the Kalmucks, and sent from thence into various parts of Russia for sale. The specific gravity of muriate of ammonia is 1.420; it is soluble in rather more than three times its own weight of water in the temperature of 60°, and in an equal weight of water when at 212°. Its solution produces cold.

According to the Baron Riedesel, muriate of ammonia is found plentifully in the neighbourhood of Mount Etna. He remarks that "the lava is not various and beautiful like that of Vesuvius, of which above forty kinds have been collected, for that the lava of this mountain contains chiefly iron and *sal-ammoniac*⁴. Wieg-
leb states, that sal-ammoniac is met with at the apertures and fissures of the internal crater of Mount Vesuvius, but that the sublimation is never observed till two months after the eruption⁵.

Basil Valentine, who wrote in the 15th century, speaks of sal-

² Rozier's *Journal*, xvi. p. 362.

³ Fourcroy's *System of Chemical Knowledge*, vol. iii. p. 274.

⁴ Riedesel's *Travels through Sicily*, translated by Foster, 8vo, London 1779.

⁵ Hopson's *Translation of Wieg-
leb*, p. 226.

ammoniac; and Geber, who lived 600 years earlier, classes it among volatile bodies, and gives directions about subliming it¹.

In the year 1773, Dr. Priestley separated the ammonia from sal-ammoniac by means of quick lime, and exhibited this alkali for the first time in the state of gas. He may therefore be said to have been the real discoverer of ammoniacal gas². This gaseous substance was afterwards examined by him in various ways, and he even succeeded in decomposing it by means of electricity; but it does not appear that he had conceived any idea of the nature of its composition, though he seems to have been well acquainted with the compound nature of the salt from which he extracted the alkaline gas. The honour of this latter discovery was reserved for Scheele and Bergman; and about the year 1785 Berthollet published a memoir which confirmed the account previously given by the foregoing chemists, that ammonia is a compound of nitrogen and hydrogen. Berthollet pronounced ammonia to be a compound of 121 parts by weight of nitrogen, with 29 of hydrogen. It is now found to consist of one proportional of nitrogen 14, and three of hydrogen 3, which will make its equivalent number 17. Muriate of ammonia, or sal-ammoniac, is composed of one proportional of ammonia 17 combined with one proportional of muriatic acid 37, and its equivalent number is 54.

Pure ammonia is known only in the state of gas. This gas has a very pungent and acrid smell, but when plentifully diluted with atmospheric air its odour is rather pleasant and refreshing; it is a colourless gas, and being much lighter than atmospheric air, it is of course volatile.

Ammonia is also caustic and corrosive, and will unite with oil into a saponaceous compound; but it has not the power of acting violently on animal substances like the fixed alkalies, potash, and soda.

Ammonia is capable of uniting with most of the acids, and forming with them neutral salts. Thus we have carbonate of ammonia, nitrate of ammonia, sulphate of ammonia, muriate of ammonia, and other salts, with this alkali for their base.

The sulphate and muriate of ammonia have been found native in the neighbourhood of volcanoes and in other parts of the globe: the triple salt called phosphate of soda and ammonia is found in human urine; and since the decomposition of sal-ammoniac has been understood, several other salts have been formed in the laboratory by its means for purposes of medicine and for various uses in the arts. Klaproth analysed a specimen of native sal-

¹ See Russel's *Translation of Geber's Works*, London 1678, p. 7.

² See Priestley's *Experiments on Air*, 8vo, London 1781, vol. i. p. 166.

ammoniac from Mount Vesuvius, and found it to be an uncontaminated muriate of ammonia, free from sulphuric acid, though the salt must have been generated in an atmosphere impregnated with sulphureous exhalations. He considers this salt to be a product of the mountain; that its basis, the ammonia, is composed of the hydrogen and nitrogen from the water, and the atmospheric air, which during that great chemical operation of nature undergo decomposition; and that this ammoniacal gas uniting with the acid gas from the decomposed muriate of soda of the sea water which finds its way into the volcano, forms the muriate of ammonia in question. The Bokarian Tartary, a district of Usbeck Tartary, in Asia, also furnishes a native muriate of ammonia. Klaproth examined a specimen of this salt, and found 100 parts of it to consist of muriate of ammonia 97.50 and sulphate of ammonia 2.50.—*Analytical Essays*, vol. ii. p. 71.

We have also fluuate of ammonia, the arseniate of ammonia, the acetate of ammonia, the oxalate of ammonia, and the phosphate of ammonia; the latter of these is much employed as a flux for the blow-pipe, and in making pastes to imitate precious stones.

None of the ammoniacal salts however are consumed or manufactured in such abundance as the muriate of ammonia, the immediate subject of this Essay; its uses and application are very general and too various to be enumerated, though the mention of a few of them will show the great importance of this saline compound.

It is employed by the dyer to moderate the action of nitric acid in the preparation of nitrate of tin, and also to modify the hue of some particular colours. The alkaline part of this salt is employed by dyers in connection with archil, an article which cannot be prepared without ammonia. It is likewise used by certain artists in the process of soldering; by the workers in copper and iron, to prevent the oxidizement of the metallic surfaces which they intend to cover with tin; in pharmacy, for the preparation of several important medicines; by the makers of snuff, in order to render that article more stimulant and poignant; and by the manufacturing and philosophical chemist, for the production of artificial cold; for analysing certain metallic substances; for the extraction of pure liquid ammonia, and for the preparation of the ammoniacal salt with which smelling-bottles are filled, and which on account of its solid form is in a variety of ways convenient and useful. I have been informed by a chemist of Birmingham, that not less than 20 tons of sal-ammoniac are annually consumed in that town by the workers in metal only.

When chemists had discovered the methods of separating the volatile alkali from sal-ammoniac, and had become generally acquainted with the nature of this gas, attempts were soon made to

discover other sources from whence it might be procured, besides that of muriate of ammonia. It had been perceived that it was frequently disengaged from animal and vegetable substances when in a state of putrefaction; it was therefore natural to examine a variety of these substances for its production, and it was soon found that fish, animal horns, bones, hoofs, &c. when submitted to dry distillation, would yield this curious and peculiar substance in abundance. It should be remembered that all the above animal substances yield ammonia exactly in proportion to the quantity of nitrogen contained in them. Dr. Austin asserts, that ammonia is always formed where iron rusts in water which has a constant communication with the atmosphere.

A plentiful source of ammonia, accessible to the people of all countries, and at all seasons, having thus been discovered, it immediately became a desideratum how to combine it, at a cheap rate, with muriatic acid, so as to form muriate of ammonia, and preclude the necessity of sending in future to Egypt for a supply of this useful and important salt; and this gave rise to the several manufactories established in different parts of Europe for this purpose.

Wiegleb, the eminent German chemist, says that the first European sal-ammoniac manufactories were established in England and Scotland; that, soon after these, one was set up at Paris by Baumé, and then another at Brunswick in Germany, in the year 1759, by two brothers of the name of Gravenhorsts, which were followed by divers others. In the year 1756, a very considerable manufactory of this salt was established by Messrs. Dovin and Hutton at Edinburgh.

When the ammonia had been procured as above mentioned, the most obvious method of forming sal-ammoniac was that of a direct mixture of the acid with the alkali; but when the first cost of the two materials, the muriatic acid and the ammonia, was considered, together with the great loss of gas which is always sustained by the mixture of these two volatile substances, it was found that the process, thus conducted, could not be carried on to any advantage in this country.

At this period however the resources of chemists had become much augmented, and every eminent practitioner in Europe was beginning to avail himself of the method of forming new substances by means of *double elective attraction*, or an interchange of principles, arising from the mixture of different compounds, one of the most valuable branches of chemical science.

Here it may be remarked, that Stahl seems to have been the first person who propagated the idea, that a compound substance could not be decomposed without the intervention of some other substance which has a superior affinity for one of the component

parts of the original compound. In the year 1718 Geoffroy published the first table of chemical affinity. This table was enlarged and improved by Gellert in the year 1750, and in the year 1775 Bergman gave to the world his inestimable treatise on elective attractions, which was published in English in the year 1785: and since then our knowledge of the subject has been much increased by Morveau, Kirwan, Wollaston, and other eminent labourers in this important department of science.

The knowledge of the property which several of the salts possess of mutually decomposing each other, naturally laid the foundation for the discovery of a more economical method of forming the muriate of ammonia, so as to avoid the great loss of gas which always happens on the direct mixture of liquid ammonia with muriatic acid, of which there had hitherto been so much complaint.

This ingenious method consists in first saturating the alkali with sulphuric acid, which may be done with little or no loss of the ammoniacal gas, and then decomposing the sulphate of ammonia which is thus formed, by the mixture of a determinate portion of muriate of soda. In this process it is observable that the sulphuric acid is not entirely lost, for it combines with the soda, and produces Glauber's salt.

The result of this mixture and of the reciprocal decomposition of the two salts just mentioned, being muriate of ammonia and sulphate of soda, it is customary to concentrate the saline mass by evaporation to that point at which, when the liquor becomes cold, the sulphate of soda will separate itself by priority of crystallization, and then to boil the remaining fluid to a dry salt, which, by an adequate degree of heat, is afterwards sublimed into solid cakes of sal-ammoniac, for sale.

By this process most of the sal-ammoniac made in this country has for many years past been prepared. But the price of the English salt has been so high, owing to the first cost of the materials and the expense of the process, that the foreign sal-ammoniac has been sold much cheaper; so that most of the consumers have given the preference to the latter, and this has occasioned the consumption of the English to be limited and very inconsiderable. This state of things has however lately undergone a complete revolution; and from some circumstances to be adverted to hereafter, sal-ammoniac can now be prepared in England as cheaply as in any part of the world.

Sal-ammoniac does not acquire any new properties by the process of sublimation. In some works on the Continent it is never sublimed, but merely inspissated by evaporation, and then moulded into the shape of a cone. In saying that the consumers preferred the *foreign* sal-ammoniac, I do not mean that this was on account of its quality, because it is undoubtedly more impure

than that which is made at home; it was its price which gave it this preponderance.

A more economical process than the one already described, for making this very important salt, was devised some years ago. This consisted in decomposing the impure solution of carbonate of ammonia by means of gypsum, or sulphate of lime; and a Mr. Minish of Whitechapel obtained a patent for the discovery. Perfectly dry sulphate of lime consists of one proportional of lime, or oxide of calcium, 28 + one proportional of sulphuric acid 40, and its equivalent number is 68.

In conducting the patent process, the rough spirit as it is called, or the aqueous product of the distillation of bones, is digested upon ground plaster of Paris; when, in consequence of a double decomposition, carbonate of lime is formed, which precipitates, and sulphate of ammonia, which remains in the solution. The fluid containing the sulphate of ammonia is then poured from the precipitate upon a definite quantity of muriate of soda (common salt), when another change takes place, which gives sulphate of soda and muriate of ammonia; and these are then treated and separated as the others, by sublimation.

This process was carried on for several years—till the term for which the patent was granted expired, when the proprietor relinquished the concern, and retired from business with an ample fortune, acquired by the manufacture of sal-ammoniac, merely in consequence of the great superiority of his process.

Another method of making sal-ammoniac was invented by Dr. Hector Campbell, which consisted in mixing the solutions of muriate of soda, sulphate of magnesia, and rough carbonate of ammonia technically called *bone spirit*. This process, in a theoretical view of it, appeared likely to be profitable, as it would give, if the decompositions were complete, three valuable products for sale, viz. sal-ammoniac, carbonate of magnesia, and Glauber's salt; but I have reason to think that it has proved otherwise, or the concern would not have been altogether relinquished. I have also some doubt as to the separation of the muriatic acid from the common salt by this mixture, because we know that muriate of soda and sulphate of magnesia are not incompatible salts, for they are constantly found together in considerable quantities in the waters of the ocean.

Much has been said at different times about the Liege process of making sal-ammoniac; which consists in mixing small sea coal, common salt, and the soot produced from pit coal, and then uniting these into a paste with tempered clay and water. The mass is afterwards formed into slabs in the form of flat tiles, and these are then placed in a furnace with bones, laid stratum super stratum, and the product of the combustion collected in appro-

prate chambers. When these furnaces are set to work, they are generally kept burning for five or six months.

This appears to me to be a better process than that of mixing the ammonia with *liquid* muriatic acid, but I am inclined to think it is too tedious an operation ever to become profitable in this country. Weber states that the soot of the Dutch turf yields also a perfect sal-ammoniac by sublimation. The Earl of Donaldald advises to mix fresh slacked lime with ground peat, and then to distill for ammonia.

In the year 1794, Lelievre, Pelletier, D'Arcet, and Giroud, eminent French chemists, were employed by the Committee of Public Safety in Paris, to make a Report on the divers means of extracting soda from sea salt with advantage; and they, in their account of that process, have given one which was at that time conducted by M. Leblanc, at St. Denis near Paris, for the manufacture of sal-ammoniac.—*Ann. de Chimie*, tom. xix. p. 58.

His method consists in decomposing muriate of soda by sulphuric acid in a kind of reverberatory furnace, the floor of which is covered with lead; and as the current of muriatic gas is determined into an adjoining leaden chamber, it is there, at the same instant, met by a current of volatile alkali, produced from a variety of animal matters, which they burn in three cylinders of iron, placed in a furnace, side by side of each other.

In this process, the vapours of the muriatic salt are condensed in the leaden chamber, not only by their combination with the ammonia¹, but also by means of an eolipile, which was heated by the same furnace in which the iron cylinders were fixed for the combustion of the animal substances.

The decomposition of the muriate of soda was not, however, entirely finished in this operation, because the sheet of lead which covered the floor of the reverberatory furnace could not, without melting, endure a degree of heat sufficiently strong to effect this purpose. The operator therefore moves the matter into a third reverberatory furnace paved with brick, where it receives a degree of heat sufficient to make it enter into fusion, and complete the decomposition. It was necessary for the proprietors of this establishment to complete the decomposition of the common salt, because the economy of their process consisted in the employment of the alkaline residuum for the production of crystallized soda.

There is, however, a mode of making sal-ammoniac, which I

¹ If the stopper be taken out of a phial of muriatic acid, in the presence of some liquid ammonia, it will be seen, by the cloud of muriate of ammonia in vapour which will appear in the atmosphere, how eager these gases are to unite to form the new compound.

conceive would be more economical than any of those already mentioned. It consists in the employment of the bittern of the salt-works, or the mother-waters which remain after the extraction of common salt from sea water. This is not a mere theoretical notion, for the process has more than once been acted upon, and at this time large quantities of sal-ammoniac are actually made according to this principle in some parts of Scotland.

The desire of making this valuable and economical process for preparing muriate of ammonia from the bittern of the salt-pans more generally known, was the motive that induced me to render the manufacture of sal-ammoniac one of the subjects of these Essays.

The preparation of this important salt by means of bittern is not, as I have said, a new process, for I recollect reading an account of it many years ago in the *Annales de Chimie*, tom. xx. p. 186, and in other works; but knowing the board of Excise in England would neither allow the use of bittern, nor even the burnt pickings of the salt-pans, free of excise duty, I imagined this to be one of those processes which are interdicted by the high price of the materials, till an accidental circumstance which occurred a few years ago recalled my attention to the subject in a very particular manner.

Mr. Astley of the town of Borrowstoness near Leith, who had taken out a patent for the manufacture of sal-ammoniac by combustion, in which he proposed to burn bones, blood¹, and other animal matters, with the bittern, proceeded by due course of law against a gentleman of the same town for having infringed his patent, and the cause came to be tried before the Lords of Session in Scotland. The question, however, not having been determined by the Court, it was agreed between the parties to defer final judgement until the opinions of some practical chemists in London should be obtained on the subject; and it was during my examination before the Commissioner appointed by the Lords of Session to take our report, that I first obtained the information that the Board of Excise allows the inhabitants of *Scotland* the bittern of the salt-works free of duty.

On acquiring a knowledge of this fact, a question immediately occurred—If the inhabitants of one part of the empire are allowed an article which is capable of being used in our manufactories duty free, why should not the same indulgence be universal in England and Ireland, as well as in Scotland?

It still however appears to me, as I suggested several years ago

¹ Dr. Thomson says, that if the fibrous part of blood be left in water it soon putrefies, and then yields more ammonia than any other animal substance.

in the Chemical Catechism, that the best situation for a manufacture of ammonia is on the sea coast, where pilchards, herrings, or the dogfish, arrive in such immense shoals as to be periodically employed in manure for land. The dogfish (the *Squalus canicula* of Linnæus) is caught all along the coast of Scotland from Peterhead to Bamff. They generally follow the herrings, and might probably be caught wherever shoals of herrings are found. The value to the fishers is in the liver, of which they make oil: therefore, the carcase, after extracting the liver, is sold for manure.

At Bamberg, in the circle of Franconia, the Germans have long been accustomed to boil the sediment of the salt-pans with stale urine, and sell it cheap for making sal-ammoniac. A similar kind of salt is still prepared in the neighbourhood of Vienna. In several other parts of Germany, and particularly in the vicinity of Gottenburgh, ammonia is prepared from the dregs which remain after the expression of train oil. Why might not the whale blubber be employed for the distillation of ammonia? Means might be devised for correcting its offensive smell, and rendering it very productive of volatile alkali.

The ingenious Mr. Dossie, already mentioned, who was a manufacturing chemist of the last century, and who had the honour of being one of the first English writers who undertook, with a noble superiority to all considerations of private advantage, to describe and elucidate many of the most important chemical processes without reserve, has, however, fallen into a considerable error respecting the use of bittern; an error which has probably misled many, and may have been the occasion of deterring some individuals from establishing the identical mode of making sal-ammoniac which I am now so anxious to explain and recommend.

The conclusion which Mr. Dossie draws, that *pure* sal-ammoniac cannot be made by the admixture of carbonate of ammonia with bittern, appears to have been occasioned by his supposing that sea-water consists only of muriate of soda and *sulphate* of magnesia: whereas, a large portion of magnesian *muriate* is also contained in it. This becomes decomposed as soon as it is added to the ammoniacal liquor, and the result, as far as the muriate of magnesia is concerned, is the formation of a true sal-ammoniac.

When urine is employed for the production of ammonia, it is necessary to keep it till it becomes putrid, this alkali being one of the products of putrefaction. In summer *one* week will generally suffice, but in cold weather it ought to be kept three weeks or a month.

It is not, however, very surprising that Mr. Dossie should have

fallen into the error respecting the bittern just noticed; for even Fourcroy, who died but lately, overlooked the magnesian muriate, and describes the waters of the ocean as containing only "muriate of soda, sulphate of magnesia, sulphate of lime, and much extractive matter¹."

The latest analysis which can be depended upon, and perhaps the best, is that by the late Dr. Murray, who obtained by the evaporation of a pint of sea water,

Common salt	180.5 grains
Muriate of magnesia	23.0
Sulphate of magnesia	15.5
Sulphate of lime	7.1
	226.1

By this estimate it appears that the proportion of muriate of lime, and muriate of magnesia, in sea-water is considerable: I am, therefore, fully justified in recommending the use of bittern for the preparation of the ammoniacal muriate, and the production of magnesia.

Another advantage will also result from the use of this refuse article, which is this, that the *sulphate* of magnesia may also be rendered efficient towards the production of sal-ammoniac; inasmuch as it will decompose the liquid carbonate of ammonia, and form ammoniacal sulphate, which, by the addition of common salt, may at any time be converted to the true ammoniacal salt of which we are now treating. If the process be thus improved and carried to its full extent, the products for sale will be sal-ammoniac, carbonate of magnesia, and Glauber's salt.

It is important to remark, that the mixture of a proportion of sulphate of ammonia with the true sal-ammoniac will, for many purposes, be no injury: for instance, the ammoniacal sulphate is well adapted to the soldering of metals, and equally applicable with the muriate of that alkali for the preparation of liquid ammonia, although it is not quite so productive of alkali.

On the nature and properties, and on the formation and decomposition of muriate of ammonia, or sal-ammoniac, the *Annales de Chimie* may be consulted, viz. Westrumb on its decomposition by magnesia and carbonate of magnesia, vol. ii. pages 118—136; Vogler on its effects with madder in dyeing linen and cotton, vol. iv. pages 115 & 144; Dr. Blagden on its use in freezing water, page 236; on its analysis, vol. xiv. page 210; Hassenfratz on its specific gravity, vol. xxviii. page 13; Fourcroy and Vauquelin on the change in the form of its crystal by its union with urea,

¹ Fourcroy's *System of Chemical Knowledge*, vol. iv. p. 409.

vol. xxi. page 67, and vol. xxxii. page 190: on its extraction from urine, page 162; Mons. Virey on its formation in volcanoes, vol. xxxvi. page 290; Vauquelin on its existence in tobacco, vol. lxxi. page 153; Berzelius on its composition, vol. lxxix. page 233, and vol. lxxxi. pages 5—13.

Since the introduction of gas lights, the principal part of the sal-ammoniac manufactured in England has been obtained from the ammoniacal liquor of the gas works, which being a cheap article and to be had in immense quantities, has almost superseded the processes described above. By the distillation of common pit-coal to procure carburetted hydrogen gas for the purposes of illumination, a considerable quantity of ammoniacal liquor is obtained in the condensing vessel. This liquor, which contains a portion of carbonate and sulphate of ammonia in solution, is sold to the makers of sal-ammoniac, who obtain the salt from it by the following process. It is first treated with sulphate of lime, and afterwards with sulphuric acid, which is added gradually until the whole of the carbonate of ammonia is decomposed, and a sulphate of ammonia formed. By subsequent evaporation of the superfluous liquor the sulphate of ammonia is obtained in crystals. At other times common salt is added to the solution of sulphate of ammonia; and this, by the play of chemical affinities, produces two new salts, viz. sulphate of soda, and muriate of ammonia. The liquor containing these two salts is then reduced in quantity, by evaporation, to that point at which it is known by experience that the sulphate of soda will separate itself on cooling. When this salt has been removed, the remaining liquor is then evaporated till the muriate of ammonia will crystallize, as has already been described at page 463. After this, the muriate of ammonia is dried carefully, and then by the usual process of sublimation, it is formed into cakes of the true sal-ammoniac. A good butt of gas-liquor, 108 gallons, which costs about eight shillings, will generally afford 94lbs of crystallized sulphate of ammonia, which when decomposed with common salt and sublimed will yield 50lbs of finished sal-ammoniac. The liquor varies in strength; but since it has become so considerable an article of commerce, most of the large gas establishments pay great attention to get it of as uniform a quality as possible.

Since the duty has been removed from common salt, and muriatic acid has become the cheapest article in a chemical manufactory, much sal-ammoniac has been made by pouring the acid at once into the gas liquor, evaporating to the proper strength, and crystallizing the muriate of ammonia, which is afterwards dried and sublimed.

With a little care and attention, the waste which was formerly

complained of as a necessary attendant on this process is nearly, or indeed entirely, obviated.

Hence an entirely new trade has arisen from the removal of an impolitic and oppressive impost. Long has the island of Britain enjoyed the blessings and luxuries which arise from an extended trade; and though we are now in the possession of the greatest part of the traffic of the world, we must not expect to preserve this proud pre-eminence, unless the Government determine to pay the most sedulous attention to our most minute interests as a manufacturing and commercial people.



Fig. 1.

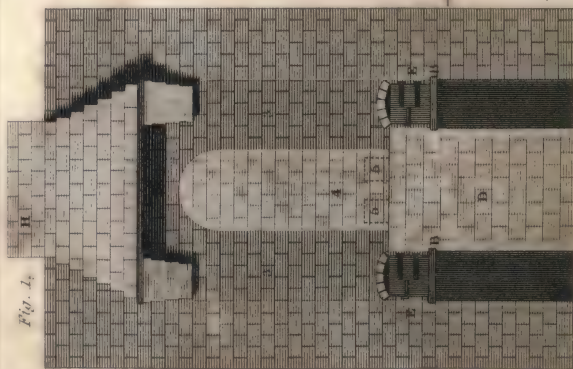


Fig. 1. Elevation.

BB. Beams for
— supporting
the grate bars
D. Foundation wall
EE. The two fire-
places
H. Chimney

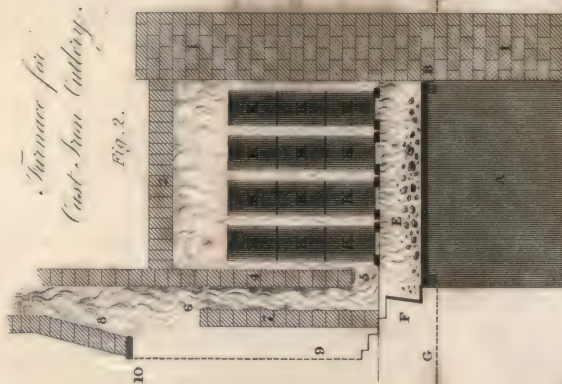


Fig. 2. Section.

A. Ash pit
B. Grate bar
E. Fire place
F. Feeder
G. Shop floor
H. Furnace wall
KK. Iron cylinder

At The Irons del.

At The Irons del.

ESSAY XV.

ON THE MANUFACTURE OF EDGE TOOLS.

THE history of the invention of EDGE TOOLS is involved in much obscurity. The materials employed by the ancients for making them were various; but the metal in general use in modern times and among civilized nations for the fabrication of such instruments, is *iron*; though this metal varies in its nature, and is differently prepared according to the purposes to which the instrument or weapon is applicable.

Although iron was known before the Deluge, yet there is reason to believe that the method of making it was afterwards lost. Tubalcain, who lived nearly four thousand years before the commencement of the Christian æra, was “an instructor of every artificer in brass and iron,” and we are told that Abraham took a *knife* to slay his son Isaac.

In these early times mention is also made of *shears*, and of the shearing of sheep; and yet many of the ancient nations knew nothing of iron, but used stones, flints, the horns and bones of various animals, the bones and shells of fish, reeds, and thorns, for every purpose in which the moderns now use edge tools of iron and steel¹.

Cutting instruments of *stone* are frequently found in various parts of South America, Asia, and Europe, particularly in the tombs of the ancient inhabitants of Peru; and in Carmania, a province of Persia, hammers frequently occur which are made entirely of stone. These are known by the name of *ceraunia*, or thunder-stones, and are preserved in some cabinets. They are perforated for the reception of handles, in the place most proper for receiving them, so as to leave no doubt of their having been intended for hammers, and used in the same way as we employ such implements at the present day².

There is a very circumstantial account of the stone weapons of the ancients, accompanied with several copper-plate engravings, in Dr. Woodward’s History of Fossils. The same writer informs us that Captain Dampier found such implements still in use at Guam, one of the Ladrone Islands, and also in Nova-Britannia,

¹ Goguet’s *Origin of Laws*, &c. vol. i. p. 140.

² Agricola *De Natura Fossilium*, lib. v. cap. 13. p. 262.

an island lying south of the equator and the furthest to the east of any then known¹.

Herodotus, in describing the ceremonies which the Arabians observe in making alliances, says, that "on these occasions some one who is connected with both parties stands betwixt them, and with a sharp *stone* opens a vein of the hand of those who are about to contract. He then takes a piece of the vest of each person and dips it in their blood²."

The ancient embalmers of Egypt were in the habit of using an Ethiopian stone for opening the dead bodies, in order to take out the bowels³; and it may be presumed, from its being the practice to circumcise with a sharp flint⁴, that edge tools of iron, if they were known, were not very common among any of the primitive nations.

Hesiod, who lived probably a thousand years before the time of Christ, says plainly, that "the plough-share was made with a species of very hard oak⁵;" and from his manner of describing the ploughs that were then employed, there is no reason to suppose that any iron was used in constructing them.

The following is a modern translation of the passage to which I allude :

"If hill or field supply an *ilex* bough,
Of bending figure like the downward plough,
Bear it away ; this durable remains,
While thy strong steers in ridges cleave the plains ;
If with firm nails thy artists join the whole,
Affix the share-beam, and adapt the pole⁶."

Dr. Kirwan, the late president of the Royal Irish Academy, who had travelled much on the continent of Europe, used to relate, when speaking of the difficulty of introducing improvements in the arts and manufactures, and of the prejudices entertained for old practices, that, in Normandy, the farmers had been so long accustomed to the use of ploughs whose shares were made entirely of *wood*, that they could not be prevailed on to make trial of those with *iron*,—that they considered them to be an idle and useless innovation on the long-established practices of their ancestors; and that they carried these prejudices so far as to force the Government to issue an edict on the subject. And even to the last they were so obstinate in their attachment to plough-shares of wood, that a tumultuous opposition was made to the enforcement

¹ Woodward's *History of Fossils*, octavo, London 1728, p. 40.

² Beloe's *Herodotus*, book iii. § 8.

³ Herodotus, lib. ii. n. 86. Goguet's *Origin of Laws*, vol. i. p. 198.

⁴ "Then Zipporah took a sharp stone," &c. *Exodus* iv. 25.

⁵ Hesiod. *Oper. et Dies*, ver. 436.

⁶ Elton's *Translation of Hesiod's Works and Days*, line 586-591.

of the edict, which for a short time threatened a rebellion in the province.

On the arrival of the Saxons in Great Britain, our ancestors were in as low a state of civilization. One of their laws enacts, that no man should undertake to guide a plough who could not make one, and that the cords with which it is drawn should be formed of twisted willows⁷.

Homer describes Achilles as offering a large quoit of iron for one of the prizes at the games instituted in honour of Patroclus; whence it would appear that this metal was still an article of considerable value.

“ Then hurl’d the hero, thundering on the ground
A mass of *iron*, (an enormous round,)
Whose weight and size the circling Greeks admire,
Rude from the furnace, and but shaped by fire.
Let him whose might can hurl this bowl, arise,
Who furthest hurls it, take it as his prize⁸. ”

Madame Dacier on this passage remarks, “ It must be remembered, that in those times *iron* was very scarce; and a sure sign of this scarcity is, that their arms were usually of *brass*. ”

If any kind of edge tools of iron were in use at this period, their employment must have been confined to but few individuals; for several ancient authors assert that Dædalus, the Greek architect, who flourished in the age immediately succeeding that in which the temple was built, knew nothing of the saw. The invention of this instrument they ascribe to the nephew of Dædalus, who, as they say, having accidentally met with the jaw of a serpent which he used with success to divide a small piece of wood, thus acquired the first idea of the use of such an implement, and soon afterwards formed a metallic instrument in imitation of it⁹.

Of all the metals, there is none which is so universally distributed over the face of the earth as iron; but the heat which is necessary for the separation of it from the ore is so intense, that we cannot wonder at many nations remaining long entirely ignorant of its use, and even of its existence; or that, when the knowledge of making it was lost at the Flood, a long period should elapse before this curious art was entirely recovered.

Accordingly, we find that spears and other instruments for exterminating wild beasts, and even implements of agriculture¹⁰, were formerly made with gold and silver; and in confirmation of

⁷ *Leges Wallicæ*, p. 283.

⁸ Pope's *Homer's Iliad*, book xxiii. line 973.

⁹ Diodorus Siculus, lib. iv. p. 319. Ovid. *Metam.* lib. viii. ver. 241. The invention of the potter's wheel is also attributed to this young architect.

¹⁰ Diodorus Siculus, lib. i. p. 19. Goguet's *Origin of Laws*, &c. vol. i. p. 153, &c.

this, Diodorus Siculus says that the Arabians, "because they have abundance of gold, and contrarily are in want of brass and iron, exchange the one for the other with merchants¹."

As the wants of mankind, however, increased, many of the purposes to which these precious metals were applied were accomplished by means of copper, this being a metal more easy to be procured than malleable iron. Thus we find that the domestic implements and most of the instruments of war of antiquity, which in our times are occasionally found in every quarter of the globe, are all either of copper or brass. Until very lately, indeed, all the edge tools that were in use in the island of Japan were of copper, or made with some alloy of that metal².

There is one circumstance, however, which shows that instruments of *steel* were known to the ancient Egyptians, and, after them, to the Greeks and Romans. What I refer to is the existence of obelisks, statues and urns of *porphyry*, which, though of undoubted antiquity, are curiously carved and engraved, in a way which could not have been effected with tools of a common temper. It has been generally understood that nothing but emery or diamond powder would touch porphyry, and I believe we have no tools at the present day that are capable of engraving it. The porphyry obelisks at Rome are however not only very curiously carved, but graven also with hieroglyphics; and though these are distinctly cut, the obelisks themselves have not suffered in the least by their exposure to the weather through so long a series of ages. This shows their extreme hardness, and how highly the tools must have been tempered by which they were sculptured and engraved. Among other notices in the 8th volume of the *Philosophical Transactions*, at page 6014, "to retrieve the art of hardening and tempering of steel for cutting of porphyry," is mentioned as an important desideratum.

In the time of the Grecian historian Agatharcides, who lived nearly two hundred years before Christ, chisels and hammers of copper were very commonly found among the rubbish of old mines: and since that period hatchets of copper have been discovered in the tombs of the ancient Peruvians³. All these may probably have been very useful utensils, especially if the fabricators of them were acquainted with any method of giving hardness to that metal.

It may here be remarked, however, that because no iron instruments of considerable antiquity are now found, we are not to conclude that the ancients never employed iron for such purposes;

¹ Cogan's *Translation*, folio, London, 1653, p. 141.

² See Goguet's *Origin of Laws*, vol. i. p. 158.

³ Many authorities for these facts may be seen in Goguet's *Origin of Laws*, vol. i. p. 158.

for it is easy to imagine that tools of iron or steel may have existed and been destroyed by the hand of time. Iron is so necessary for the support of animal and vegetable life, that nature has endowed it with an affinity for oxygen, carbon and sulphur, much greater than that of most other metals, in order that it might be universally distributed. It is therefore difficult to conceive how an implement of iron could lie in the ground for a thousand years without being destroyed.

If we inquire respecting the state of the metallic arts among the ancient Britons, it will appear, from the prodigious numbers of copper instruments of different sizes and kinds which have been found in this country, such as axes, swords, spear-heads, arrow-heads, &c., all of which are known among antiquaries by the general name of *celts*, that our ancestors were well acquainted with the art of forming metallic copper in any way which they thought proper¹.

So lately as the year 1735, more than one hundred of these copper celts were found on Easterlymoor, twelve miles from the city of York, together with several lumps of metal intermixed with a quantity of foundry cinders, so that there can be no doubt of there having formerly been a forge at that place for making such articles².

The war-chariots of the ancient Britons afford abundant proof that they were expert in the working of metals as well as in the modelling of wood. "The *covinus*," says Dr. Henry, "was a war-chariot, and a very terrible instrument of destruction, being armed with sharp scythes and hooks for cutting and tearing all who were so unhappy as to come within its reach. It held few men, but was designed to be driven with great force and rapidity and to do execution chiefly with its hooks and scythes³."

Notwithstanding the abundance of iron ore which this country affords, it appears that the use of metallic iron is comparatively but of late introduction : for at the time of the first Roman invasion, this metal was so scarce and rare a commodity that the Britons fabricated their money with it, and even the trinkets for adorning their persons⁴. But when the Romans had made themselves masters of the country they established imperial foundries for making iron, and built forges for manufacturing spears, lances, battle-axes and implements of every kind, in different parts of the kingdom.

¹ See Leland's *Itinerary*, vol. i. p. 127. Henry's *History of Great Britain*, vol. ii. p. 138.

² Borlase's *Antiquities of Cornwall*, p. 283.

³ Mela, lib. iii. cap. 6. Tacitus, *Vita Agricolaë*, cap. 36.

⁴ Cæsar, *de Bello Gallico*, lib. v. cap. 12. Henry's *History of Great Britain*, vol. ii. p. 139.

Accordingly we find that the offensive armour of the cavalry in the time of William the Conqueror was a long spear or lance pointed with *steel*, very sharp and well tempered; the long and broad sword double-edged, and a short dirk or dagger¹.

The art of working in iron and steel had arisen to such a state of improvement in the 10th century, that even the horses of some of the chief knights and barons were covered with steel and iron armour. Artificers who wrought in iron were so highly regarded in those warlike times, that every military officer had his smith, who constantly attended his person, to keep his arms and armour in order. The chief smith was an officer of considerable dignity in the courts of the Anglo-Saxons, and Welsh kings, where he enjoyed many privileges, and his weregeld was much higher than that of any other artificer. In the Welsh court the king's smith sat next to the domestic chaplain, and was entitled to a draught of every kind of liquor that was brought into the hall.

The skill which our ancestors acquired under the instruction of the Romans, seems never to have been lost; for at the battle of Hamildon in the year 1402, the repulse of the Scots appears to have been entirely owing to the goodness and excellent temper of the arrows which were employed by the English army. Even the armour of the Earl of Douglas, which had been three years in making, was perforated by them; for, as the account states, "they were so sharp and strong that no armour could repel them"².

Dr. Martin Lister was of opinion that the ancients made their instruments *hard*, and converted them into *steel*, by one and the same operation; that they first fashioned them out of good soft wrought-iron, and then boiled them, as he expresses it, in fluid cast-iron. I have no doubt that good steel might be made by this process³.

We read but little of *swords* in the beginning of the 15th century, though no doubt they were then in use, since there is the evidence of Geoffrey Chaucer, who died only two years before the memorable battle of Hamildon was fought, that Sheffield was, even then, famous for its cutlery:

"A dagger hanging at his belt he had,
Made of an ancient sword's well tempered blade;
He wore a *Sheffield* whittle in his hose."

Canterbury Tales.

Table-knives, which probably were not in use in the time of Chaucer, were first made in London in the year 1563, by one

¹ Hoveden's *Annals*, p. 350, col. 1.

² Walsingham's *Historia Brevis*, p. 366. Henry, vol. x. p. 193.

³ See *Philosophical Transactions*, vol. xvii. p. 865.

Thomas Matthews of Fleet-bridge⁴. I have not been able to ascertain the date of the introduction of other kinds of cutting instruments; but when the utility and convenience of these domestic implements were once experienced, there can be no doubt that the practice of using them quickly became very general, and that manufactories of knives and other edge tools were consequently soon established in various parts of the kingdom. But in whatsoever manner this may have been, what has been offered will suffice to give the reader some idea of the progress of the art of cutlery, and of its gradual introduction into this country.

It is time now, however, to say a word or two respecting the design of this Essay, which is principally intended to explain some of the most important of the modern processes in *tempering* edge tools, and to point out such improvements as have occurred to me while examining some of the manipulations of the various artists who are now employed in the different branches of cutlery, and in the manufacture of steel⁵, both in its cementation and the operation called *tilting*.

Good edge tools cannot be made without steel, which, according to the analysis of Vauquelin, is generally nothing more than soft iron combined with a small portion of carbon, silica and phosphorus, and sometimes a minute quantity of manganese⁶. Steel acquires the magnetic property better than iron. Hence good mariners' compasses cannot be made without needles of steel. The different kinds of steel may in some measure be known by their specific gravities⁷. The smell of putrid garlic, which is emitted by steel when dissolving in diluted sulphuric acid, is probably owing to the small portion of phosphorus contained in this compound metal.

Our makers of steel always use Swedish iron for this purpose. That which comes from Roslagen, a district in the neighbourhood of Upsal, is the best. The steel which is produced from it is, in its first state, denominated *blistered* steel. A very particular account of the method of making steel at Dalecarlia in Sweden, will be found under the article *Steel* in Keir's Translation of

⁴ See *The present State of Great Britain*, London 1683, p. 77.

⁵ For an account of the methods of making steel consult Cramer's *Elements of the Art of Assaying Metals*, octavo, London, 1741, p. 344–350; the article STEEL in Macquer's *Chemical Dictionary*, vol. iii.; or Chaptal's *Chemistry applied to the Arts*, vol. ii. p. 197.

⁶ Vauquelin, from the *Journal des Mines*, in Nicholson's *Quarto Journal*, vol. i. p. 210.

⁷ See Dr. George Pearson's Memoir in the *Philosophical Transactions* for 1795, p. 324.

Macquer's Chemical Dictionary. The various sorts of steel are made by very different managements, and are thus rendered suitable for as many different purposes.

It may, however, be noticed that the largest English steel-works are at Newcastle-upon-Tyne, at Masbro near Sheffield, at Stour-bridge, at Birmingham, and at the Brades. At Newcastle between twenty-five and thirty thousand weight of steel is cemented at a single operation, in two cases contained in one furnace. The operation lasts five days and five nights.

There are five kinds of steel generally employed in this country; viz. *blistered*, *shear*, *spur*, *star*, and *cast steel*. The cheapest sort of edge tools, and all articles of minor importance, are usually made with the first-mentioned kind, united to a large proportion of bar-iron. Clothiers' shears, firmer chisels, plane-irons, coopers' adzes, scythes, reaping-hooks and large knives, are commonly made with what is called *shear* steel. The *spur* and the *star* steel are used only for particular purposes, and these according to the fancy of the master cutler. Besides these, there is also a German steel which is made immediately from the iron ore, by simple fusion. Vandermonde and his associates have published an account of the mode of producing it ¹.

Shear steel is prepared by a peculiar process. Several bars of common steel are laid together and regularly heated in an appropriate furnace, until they acquire the welding temperature, when they are beaten together by a massy forge-hammer, and then drawn out again into bars for sale. By this second operation the blisters are removed, and the texture of the metal is much improved.

Mr. Joseph Collier to his observations on Iron and Steel in the Manchester Memoirs, vol. v. p. 109, has annexed a drawing of a furnace for converting bar-iron into steel, with a full description thereof, which is worth the attention of persons interested in this subject. An abstract from this paper, together with the plate, may be seen in Nicholson's Journal, vol. iii. p. 88.

The different kinds of iron and steel vary very much in price. The following are about the present prices of most of the sorts in the London market.

Common bar iron, 7s. and 8s. per cwt.

Best Swedish iron, 16s. and 18s. per cwt.

Common steel, usually called blistered steel, 52s. per cwt.

Shear steel,

Star steel,

Spur steel,

} 68s. to 88s. per cwt. according to the sizes.

¹ See Nicholson's Quarto Journal, vol. ii. p. 64.

Cast steel rolled into sheets, 60s. per cwt.

Cast steel drawn into bars, 88s. to 100s. per cwt. according to size.

The high price of Swedish iron is owing to the great superiority of its quality when compared with common English iron; and this is attributed to the circumstance of its being manufactured with *wood* charcoal, whereas most of the English iron is prepared by means of mineral coke. The Swedish iron, however, differs very much in its quality; even one part of the same bar will often be of much greater value than the other. Formerly the wire-workers in Yorkshire used to go to Sheffield to buy foreign iron, on account of the circumstance above mentioned: it was usual with them to cut the bars into two-foot lengths, and then to select only such pieces as were fit for their purpose, leaving the other to be converted into steel. It is no uncommon thing to find a bar of foreign iron tough on one side and quite hard and brittle on the other. If such iron be exposed to the weather, this would soon become apparent by one side rusting and the other remaining quite clean, owing probably to the unequal distribution of the carbon in its manufacture.

I have also been informed that we have no artist in England who can make iron-wire fit for musical instruments, and that all such wire is imported from Holland, and sold at very extravagant prices. The larger kind, such as is used in a piano-forte, cannot be bought for less than 8*d.* or 10*d.* per ounce.

With regard to *cast* steel, the best penknives, scissors and razors, fine saws, surgical instruments, and every edge tool which requires a fine polish, together with a great variety of implements employed in cutting iron, are now all made with cast steel.

There are several cogent reasons for the preference of cast steel, for its nature is totally different from that of every other species. The proportions of the substances which combine with iron to convert it into steel are comparatively very minute; it is therefore necessary that these should be intimately and uniformly blended with the whole mass, and this is better effected by fusion than in any other way. By the fusion which this particular steel undergoes, the grain becomes closer, and the metal consequently much harder. These causes are sufficient to account for cast steel bearing a higher polish than most other kinds.

The superior beauty of those instruments which are made with cast steel would have occasioned a very great consumption of this article, had it not been for the difficulty of welding or uniting it properly with iron, and which, at first, occasioned it to be employed only for those smaller instruments, such as lancets and penknives, which are generally made entirely of steel.

However, it is necessary to be a little more explicit on this

part of our subject. Bar-iron cannot be welded to another piece of iron unless both be heated to nearly 60° of Wedgewood's pyrometer, which is equal to 8.877° of Fahrenheit's scale, and is called the *welding-heat*; but if cast steel be heated to this point, it would be fused, and run from under the hammer; and hence it was for a long time deemed impossible to use it in conjunction with iron, in the same manner as the other kinds of steel are employed.

Some nicety is required even in the process of welding iron, that the outside of the metal does not oxidize too much and fly off in scales, before the inside is brought up to a welding-heat. When therefore a skilful workman is about to weld two pieces of iron, he carefully observes the progress of the heat; and if one becomes too hot, he rolls it in sand to preserve it from the action of the atmosphere; and when one piece acquires the necessary temperature before the other, he covers that with sand while he brings the corresponding piece up to a sufficient heat for it to unite properly with the former. Silica when mixed with the oxide of iron forms a very fusible compound, which covers the work under operation, and prevents a further oxidation of the metal.

I have said that it was formerly deemed impossible to unite cast steel to iron by welding; but about thirty years ago it was discovered by Sir Thomas Frankland, who made many experiments on this subject, that if the cast steel be made only of a *white-heat*, and the iron of a welding-heat, the steel will then be soft enough to unite with the iron, and yet the former will not become fluid by the operation. It will, however, be proper to give the necessary temperatures to the two metals separately, and then to unite them at one single heat. Phil. Trans. 1795. p. 296.

Since this important discovery, cast steel has been brought into more extensive use, and the instruments which are thus constructed are much better than those which are made entirely of cast steel. The circumstance of an instrument having its back made of iron, renders it not so apt to fly from the work to which the edge or steel part is applied, and eventually less liable to break.

Mr. Nicholson, in his annotations on a Memoir by Vandermonde and others, informs us, he is convinced from his own experience that *cast* steel is preferable not only for polished steel goods, but also for cold chisels and all hard gravers for turners in metal.

I have been the more desirous of mentioning these particulars, because, on a late journey into the country, I have conversed with several ingenious cutlers, who had no idea that it was possible to unite iron and cast steel by the operation of welding. Many

artists, long after the invention of cast steel, used to unite it to the iron by means of rivets. Hoes are still made by riveting or screwing the back, together with the eye, upon a blade made with cast steel.

Besides the various sorts of steel already enumerated, there is a peculiar kind which is manufactured at Bombay, called *wootz*, which admits of a higher temper than any other steel. Mr. Stodart of the Strand forged a piece of wootz for a penknife, at the temperature of ignition in the dark. It then received the requisite temper at 450° , and the edge became as fine, and cut as well, as the best steel instrument. From this experiment, this ingenious artist gave it as his opinion that wootz is superior, for many purposes, to any steel used in this country. He thought it would carry a finer, a stronger, and a more durable edge and point, and that hence it might be particularly valuable for lancets and other fine chirurgical instruments¹.

Mr. Mushet of the Clyde Iron-works has written an interesting paper on the properties of wootz, in which he gives an account of the separate analysis of five cakes of this foreign production, which he undertook at the desire of Sir Joseph Banks and sent to the Royal Society. In concluding this important communication, he makes the following remarks on the East Indian ore from which wootz is made: "The possession," says he, "of this ore for the fabrication of steel and bar-iron, might to this country be an object of the highest importance. At present," he adds, "it is a subject of regret, that such a source of wealth cannot be annexed to its capital and talent." *Phil. Trans.* vol. xcv. p. 175.

The methods which are employed in making edge tools, are almost as various as the articles themselves. It cannot, therefore, be expected that I should describe in detail, or even completely understand, the nature of every process, especially as I was never personally engaged in any branch of the manufacture. The enumerating of a few of the more important of the manipulations, on which the artists chiefly rely, will, I trust, be deemed sufficient.

The cooper's adze and the carpenter's axe are first formed by the white-smith in iron, together with the eye for the helve. This being finished, the instrument is again heated, and then the edge of the cutting part is slit down with a chisel, and this slit filled with a thin piece of steel, of a corresponding size and form. The iron which had been slit open is then folded down upon the steel, and the whole is again submitted to the action of the fire till the

¹ See an account of experiments on wootz, in the 85th volume of the *Philosophical Transactions* for the year 1795, p. 322—326. Mr. Faraday on the Analysis of Wootz, in *The Quarterly Journal of Science*, vol. vii. p. 288.

metal acquire a welding-heat, when the sledge-hammer quickly unites the iron and the steel into one compact mass. When the white-smith is desirous of finishing these implements in the best manner, he allows them to be beaten on the anvil more than is absolutely necessary for putting them into the proper form, because the more the metal is hammered the tougher it becomes. This is the chief reason why horse-nail *stubs* are chosen for making chains and other works in iron which require great tenacity¹.

Scythes and such other large instruments are forged at the mill, by means of a large hammer moved by water. The process is called *skelping*.

Augers, gouges, large chisels, table-knives, razors, and other instruments of a similar bulk, are forged upon a large anvil by the principal workman, aided by an assistant called the *striker*, who stands on the side of the anvil opposite to that where the chief operator stands, and puts in a heavy blow with a sledge-hammer occasionally, while the former is fashioning the instrument with a small hand hammer, and turning it round on the anvil, that it may receive now and then a blow from the sledge-hammer on those places where he perceives that it is required. This is usually done with considerable adroitness, and by these means such instruments are fashioned in a quarter of the time that would be necessary for the purpose if they were forged by a single workman.

For making the articles which are enumerated in this list, shear-steel is generally employed, as it is necessary such instruments should be entirely free from flaws; and this would not be the case were the common steel to be used for them. A facility is given to the forging of razors and some other instruments, by the steel being previously drawn out to a correspondent size at the tilting-forge.

Penknives, lancets, gravers, surgical instruments, and other small edge tools, are generally forged on a small anvil firmly fixed within a large one in order to give greater steadiness. These are usually fashioned out of steel only, and forged by one workman singly and alone. Scissars are also forged by a single hand: but the anvil on which they are fashioned is of a peculiar construction, having *bosses* or *dies*, and *beak*-irons of various sizes occasionally adapted to it, so as to suit the different shapes and dimensions of the separate parts of these particular instruments.

The beak-iron, or bickern as it is sometimes called, is a round taper instrument fixed upon an anvil in an horizontal direction,

¹ The method which is adopted of converting old nails into bar-iron is curious, and may be seen fully described in Aikin's *Chemical Dictionary*, vol. i. p. 600.

and designed for fashioning hollow work upon, which could not be beaten upon the straight face of the anvil. Some anvils have beak-irons adhering to them, and others have square holes at one end for a moveable beak-iron to drop into.

It should have been noticed, that many other tools besides the axe and the adze are originally forged out of a piece of iron, with a little steel welded to it for the cutting part of the instrument. I have also heard of one instance in which the steel is affixed to a tool of *cast* iron, and that an excellent instrument is produced by this method. This is in the manufacture of Bingley's patent plane-irons, which are constructed in the following manner.

It is well known that it is the circumstance of drawing down the *shear*-steel under the tilt hammer that gives it the superiority over common steel. Mr. Bingley therefore thought that, if he could roll out his steel much thinner than it had ever been done before, he should improve its quality; and accordingly a very thin piece of steel is let into the face of a plane-iron made of cast-iron; and, as the steel for this particular purpose has to go through the rollers several times to make it sufficiently thin, it becomes of a peculiar texture, and the tool made with it is found to suit the joiner much better than the plane-irons heretofore in use.

In the manufacture of edge tools, the process which immediately succeeds the forging is that of *hardening*. All these cutting instruments are therefore fashioned when the metal is in its originally soft state; and when they have attained the intended forms, they are heated afresh to a particular temperature suitable to the article. When they have acquired that degree of heat, they are instantly plunged into cold water, which gives them great hardness, and renders them capable of cutting soft iron or even steel.

The best cutlers have ascertained that it is always desirable not to give an instrument a greater degree of heat by this operation than is absolutely necessary; but this will be better understood as we proceed in describing that process.

Nothing augments the hardness of steel but increasing the *coldness* of the water; and hence some have had recourse to the solution of salts in the water to be employed in hardening. A stream of running water will make steel harder than *still* water, as fresh portions of the same fluid are incessantly presented to the heated metal. Some cutlers have assured me that they can make the best instruments when they employ urine in the process of hardening. May not this be attributable to the phosphoric salts contained therein, as it has been demonstrated that phosphorus is one of the component parts of steel?

It is now generally understood that hardening by means of the

strong mineral acids has no peculiar advantage; but I find that Reaumur, from his own experience, recommends the use of diluted nitric acid¹. For the discoveries which this eminent man made respecting the conversion of iron into steel, the Duke of Orleans settled a pension upon him of 12,000 livres a year; and, at his request, this was settled upon the Academy, to be applied after his death for defraying the expenses of future attempts to improve the arts².

Experience has proved that instruments which are the hardest acquire the keenest edge and are the most capable of cutting; but then a great degree of hardness always occasions the metal to be brittle; and when the edge is very fine, such instruments are useless for dividing hard substances, because the sharp part is not tenacious enough to endure the operation without snapping asunder. It is necessary therefore to be content with less hardness in order to obtain the requisite tenacity, and this is effected by the operation called *tempering*.

Hence, when an instrument has been properly hardened, it must be softened again in some measure, or to that degree which is thought to be most suitable for that particular purpose for which it is intended. To effect this, it is heated again only to a certain point, which is usually determined by the colour which the metal assumes, and then it is instantly plunged into cold water. This is called letting it down to the proper temper.

In France it has been the practice, in hardening small steel instruments, to cover them with soft soap and then to roll them in common salt. This treatment prevents the articles from scaling, and does not prevent the hardening. The salt fluxes to a glass which covers the metal and protects it from oxidizement³.

Pliny informs us, that in his time the more delicate iron instruments were steeped in oil to quench them, lest they should grow too hard and brittle with water⁴. On the contrary, Jonston says that "if iron be plunged in vinegar it will endure no hammering, but will sooner break than draw⁵." The Lacedæmonians, who made their coins of iron rods, were used to steep them in vinegar when red hot, that, being thus rendered brittle, they might never be put to any other use⁶.

Mr. Rhodes, an eminent cutler of Sheffield, has published some very important observations on the process of hardening steel.

¹ See *L'Art de convertir le Fer en Acier*, par M. Reaumur, p. 359.

² Chalmers, vol. xxvi. pp. 93, 94.

³ Berthoud's *Treatise on Marine Clocks*. 4to, Paris 1773.

⁴ Pliny, lib. xxxiv. cap. 14.

⁵ Jonston's *History of the Things of Nature*, p. 123.

⁶ Plutarch in *Vita Lyncurgi*.

“Articles manufactured of steel for the purposes of cutting,” says Mr. Rhodes, “are, almost without an exception, hardened from the anvil; in other words, they are taken from the forger to the hardener without undergoing any intermediate process; and such is the accustomed routine, that the mischief it contains has escaped observation. The act of forging produces a strong scale or coating, which is spread over the whole of the blade; and, to make the evil still more formidable, this scale or coating is unequal in substance, varying in proportion to the degree of heat communicated to the steel in forging; it is, partially, almost impenetrable to the action of water when immersed for the purpose of hardening. Hence it is that different degrees of hardness prevail in nearly every razor manufactured: this is evidently a positive defect; and so long as it continues to exist, great difference of temperature must exist likewise.”

“Razor-blades not unfrequently exhibit the fact here stated in a very striking manner: what are termed clouds, or parts of unequal polish, derive their origin from this cause: and clearly and distinctly, or rather *distinctly* though not *clearly*, show how far this partial coating has extended, and where the action of the water has been yielded to, and where resisted. It certainly cannot be matter of astonishment, that so few improvements have been made in the hardening of steel, when the evil here complained of so universally obtains, as almost to warrant the supposition that no attempt has ever been made to remove it. The remedy, however, is easy and simple in the extreme, and so evidently efficient in its application, that it cannot but excite surprise, that, in the present highly improved state of our manufactures, such a communication should be made as a discovery entirely new.

“Instead of the customary mode of hardening the blade from the anvil, let it be passed immediately from the hands of the forger to the grinder; a slight application of the stone will remove the whole of the scale or coating, and the razor will then be properly prepared to undergo the operation of hardening with advantage. It will be easily ascertained, that steel in this state heats in the fire with greater regularity, and that when immersed, the obstacles being removed to the immediate action of the water on the body of the steel, the latter becomes equally hard from one extremity to the other. To this may be added, that, as *the lowest possible heat at which steel becomes hard is indubitably the best*, the mode here recommended will be found the only one by which the process of hardening can be effected with a less portion of fire than is, or can be, required in any other way.”—“These observations are decisive, and will, in all probability, tend to establish in general use what cannot but be regarded as a very

important improvement in the manufacturing of edged steel instruments¹."

It has always been difficult to explain how the water acts in hardening iron and steel; it is a subject that has ever been involved in obscurity, and I do not recollect to have seen any plausible conjecture or theoretical view offered upon it.

I am desirous, before we proceed with the subject, to make one observation on the property which iron possesses, almost exclusively, of acquiring various degrees of hardness and of becoming soft again at any time, as occasion may require.

It should be remembered, however, that steel differs from iron in this circumstance,—that if it be made red-hot and then immediately plunged into cold water, it becomes much harder than it is possible to make iron by such treatment. It may however at any time hereafter be softened again, merely by heating it afresh and then allowing it to cool gradually.

The property which iron and platinum possess of welding is very important, as has before been remarked; but were it not for this singular quality in iron, of being hardened and softened at pleasure, and which seems to me to be a striking and peculiar adaptation of a material to the uses for which it was originally designed, none of the arts dependent upon the uses of this metal could have been brought to the perfection which they have now attained; and if it were possible for iron and steel to lose this property of becoming hard and soft, such arts, however complete they may now be, would be lost with it.

I recollect having been very forcibly impressed with this idea when I first visited a manufactory of printers' types. There the largest steel punches which are employed in making the brass moulds for receiving the type-metal, and some of these are very heavy, are all formed by other punches; and the largest and deepest letters are cut out in this manner, by main force. As these tools of steel are not hardened till they are completely formed by others that are already hardened, the latter cut out the former with as little difficulty, to all appearance, as if they were operating upon a piece of tin or lead; and yet these same articles, which are cut with so much ease, require only to be submitted to the hardening process, and then they will be as capable of operating upon soft iron or steel, and of cutting either of them as readily into any shape, as they were themselves cut when in their original state of native steel.

Here I should be guilty of great injustice if I were to omit to notice the improvements in softening and hardening iron and

¹ See an *Essay on the Manufacture of a Razor*, by E. Rhodes, cutler, Sheffield, 8vo, p. 20.

steel which have been discovered by Messrs. Perkins and Fairman of London, and employed by them in preparing steel plates on which they engrave bankers' notes. The methods are kept secret; but Mr. Brande has published a very curious and interesting account of what the inventors have been enabled to do by these means, accompanied by a most beautiful specimen².

In the manufacture of edge tools the most important process, as was before mentioned, is that of tempering. But, to effect this in the best manner possible, there must be, as Mr. Nicholson³ has happily expressed it, "a precise mean between too soft and too brittle, which will be best suited for the respective purposes to be accomplished. A spring must be tenacious, and need not be very hard. A knife for cutting leather and other soft substances must be somewhat harder than a spring. Penknives and razors must be still harder; and files and tools for working metal must be hardest of all; though, even in these, care must be taken not to destroy their tenacity by making them too hard."

Hence it will be apparent that great nicety must always be observed in the operation of tempering; and if due care be not taken, there can be but little chance of the instruments ever fulfilling the respective purposes for which they are designed. The temper of a lancet is generally the highest of any polished steel instrument, and therefore it is merely owing to its being so very thin that it springs a little at the extreme point.

The usual mode of ascertaining the temperature to which any edge tool has arrived, is by attending during the operation to the shades of *colour*, which, as the metal becomes more and more heated, the bright parts assume in rotation, and then when it has acquired that particular hue which may be desired, removing it from the fire into water. But the nature of the operation is such, that this must always be attended with some uncertainty, especially as different tools require different management in the process, and it is often a very uncertain task to give the same temperature to every part of the same instrument.

It was on account of these and some other difficulties which the makers of edge tools constantly labour under, that I was induced to turn my attention to the subject, trusting that I should be enabled to suggest to the unscientific cutler, some improvement in this most important though very uncertain branch of the art. But, in order that the reader may be better able to appreciate what I have to propose, I shall first show what particular colours are usually required for the tempering of a few of the instruments

² *The Quarterly Journal of Science*, vol. ix. p. 124.

³ Nicholson's *Quarto Journal*, vol. i. p. 381.

which are most in demand, and then explain some of the methods now practised for the attainment of some peculiar purposes.

This detail of the gradation of colours, I have copied from Mr. Nicholson's account of some experiments by Mr. Stodart¹, and from Mr. Aikin: but the opinions of scientific men on the cause of these variations of colour, have been very different; and in my opinion all of them are very unsatisfactory. Sir Isaac Newton supposed that the size of the metallic particles must have been altered by the action of the fire. Later writers have attributed these changes to the different degrees of oxidizement which the steel undergoes; and M. Prieur has endeavoured to account for them by supposing that they are occasioned by an alteration in the arrangement of the particles, and that the colours are apparently in concentric rings. This he has endeavoured to explain by the feathers of the peacock, the neck of the pigeon, the duck's wing, &c.²

In tempering edge tools, the first colour, which appears at 430° of Fahrenheit, is very pale and only a little inclining to the *yellow*; this is the temperature at which lancets are usually tempered.

At a little higher temperature, say 450°, the pale *straw* colour appears, which is a heat suitable for the best razors and most of the surgical instruments. Then comes the *full yellow*, at 470°, which is proper for common razors, penknives, and some other implements of surgery.

By increasing the temperature to 490°, the *brown* colour will be produced, which is generally looked for by those who have to temper garden-hoes, small shears, and scissars, and all those chisels which are designed for cutting *cold* iron. Then at 510° comes the brown, dappled with *purple spots*, which shows the proper heat for tempering axes, firmer-chisels, plane-irons, and pocket-knives. The next colour in succession is the *purple*, at 530°, the heat at which table-knives and large shears are usually tempered. The next is the *bright blue*, at 550°, which will give a proper temper to swords, watch-springs, springs for trusses, bell-springs, &c. Then comes the *full blue*, at 560°, which being the highest spring temper is usually employed for small fine saws, daggers, augers, &c. This is the proper heat also for tempering most of those instruments which require to be elastic. The last degree in succession is the *dark blue* approaching to black, which shows itself at 600°, and is the softest of all the gradations of temper, when the metal becomes suitable to few other instruments than hand and pit saws, which are necessarily made very soft in

¹ Nicholson's *Quarto Journal*, vol. iv. p. 129.

² *Annales de Chimie*, tome lxi. p. 154—179.

the first instance, that the workmen may be able to file them up and set them whenever they find occasion for it, without being obliged to soften them every time that operation is to be performed. This great heat is likewise employed in tempering some particular kinds of springs.

Some curious facts respecting the properties of *blued* steel are related by Mr. Nicholson on the testimony of Mr. Stodart, who says "that he has found the spring or elasticity of the steel to be greatly impaired by taking off the blue with sand-paper or otherwise; and, what is still more striking, that it may be restored again by the blueing process, without any previous hardening or other additional treatment³."

Extraordinary as these facts may appear, they have been fully confirmed by a manufacturer of Sheffield, who signs T. B. (probably Mr. Boulsover) and who writes thus:—"I took," says he, "a steel plate 30 inches long, 12 broad, and about .04 thick; I hardened it in a composition of oil and tallow, and afterwards tempered it down to a spring temper; it was now so elastic as to recover its position after being bended—by hammering it to set it straight, it lost a part of its elasticity; after being ground in the same manner as a saw, the elasticity became still less, having nearly returned to the same state as before hardened:—it was then very uniformly heated until it became blue; it now recovered the whole of its elasticity:—after being glazed bright upon a glazier coated with emery, the elasticity was found to be impaired, but in a less degree than when it was ground;—the same effect was also produced by rubbing with emery or sand-paper, and also by burnishing; invariably the elasticity was recovered by blueing, and hence this is always the last operation in the manufacture of elastic steel plate⁴."

Every maker of edge tools well knows that their temper is indicated by the colour which they assume; thus by observing the progress of the colours, he is guided in operating on the different kinds of instruments, experience alone being the rule in these cases; but in order to obtain the most favourable results in some instances of nicety, there are other minutiae which require much care and observation.

Thus, in tempering penknives and other tools which have a *thick* back and a very *fine* edge, they are always laid with the backs downwards, either in heated sand or on a hot iron plate; otherwise they would become too soft at the edge, before the backs could be entirely heated.

In hardening knife blades it is usual to plunge them perpen-

³ Nicholson's *Journal*, vol. xii. p. 63.

⁴ *Ibid.* vol. xiv. p. 266.

dicularly into the water, to prevent their warping by being cooled with too great rapidity. And here it may be remarked, that if steel be heated only to that point when it begins to become red in the dark, and then plunged into cold water, such metal will not become hard. The heat for hardening must indeed be so great, that in winter the workman is obliged to take the chill off the water before the goods are immersed in it, to prevent them from cracking by the suddenness of the transition. Mr. Stodart says that one of his workmen makes up his charcoal fire with shavings of *leather*, finding that this is effectual in preventing the tools from cracking by this process.

For the best methods of preventing the warping of steel instruments in the operation of hardening, a paper by Mr. E. Lydiatt may be consulted with advantage; there are few cutlers who could not derive some valuable information from its perusal¹.

For hardening very small instruments various other schemes have been adopted. Thus, fine drills and small gravers are hardened by heating them with a blow-pipe over a candle, and then running them instantly into the body of the same candle. In this way only one instrument can be hardened at a time; and as such minute tools would be cooled too much before they could possibly be immersed in water, this expedient has been adopted, and succeeds sufficiently.

Formerly some cutlers employed suet, oil, solutions of sal-ammoniac and other salts for immersing the heated goods into in the process of hardening; but these methods are now, I believe, all abandoned. Mr. Nicholson has stated that "Mr. Stodart has not found that any advantage is obtained from the use of salt in the water," though he adds that "questions respecting the fluid to be used in hardening are, properly speaking, applicable only to files, gravers, and such tools as are intended to be left at the extreme of hardness²." It was found, indeed, that oil had an injurious effect, and that such cutting-instruments as had been hardened by being plunged into cold oil would never take a fine edge.

I know, however, an artist who makes a large quantity of truss and other springs, and who has very ingeniously taken advantage of this property which oil has of giving steel a coarse grain. He conceived that if the steel were less compact than usual, such springs would have greater elasticity; and this he has long found to be the fact: he therefore now hardens all his springs by heating them till they acquire the full blue colour, and then plunges them into a vessel of cold linseed oil.

¹ See Nicholson's *Journal*, vol. xxxiv. p. 31.

² Nicholson's *Quarto Journal*, vol. iv. p. 128.

Saw-makers temper their goods in a different way. They rub them over with suet or other grease, and then heat them gradually until the temperature of each tool is raised sufficiently to set fire to the grease of itself, and occasion it to blaze. By this means they are thought to acquire a temper equal to what would be obtained by heating them in the usual way till they became of a deep blue. The operation is called *blazing*. The great manufactory of saws is at Sheffield, and there this practice is observed. It usually brings the article to the temperature of about 600° of Fahrenheit.

Mr. Hardy, a skilful artist, who has written on the construction of Time-pieces, says, "that the saw-makers first harden their plates in the usual manner, in which state they are more or less contorted or warped, and are brittle,—that they then blaze them; which process deprives them of all springiness, so that they may be bended and hammered quite flat, which is a delicate part of the art of saw-making;—and that they blue them on a hot iron, which renders them stiff and springy without altering the flatness of their surface." He adds, that "soft unhardened steel may be rendered more elastic by blueing, and that hard steel is more expansible by heat than soft³."

I know of no instruments, however, which require so great nicety in hardening, as the files which are intended for sharpening carpenters' hand-saws. The saws themselves being made of cast-steel are extremely hard, and therefore the file must be still harder before it can make any impression upon them. But there is a difficulty attending this process, namely, that if these small instruments be made any harder than is absolutely necessary, they become brittle, and their teeth will be liable to fly at every stroke. I mention this, because I consider that a method of bringing these small tools to a proper temper, *with certainty*, is an object well worth the pursuit of persevering and ingenious men.

In file-making, the great desideratum is to unite tenacity with hardness. If steel for this particular purpose were made with *animal* instead of *vegetable* charcoal, this excellence might probably be attained.

It is rather a digression from the subject of hardening steel instruments, but it may be acceptable to several of my readers, to mention, that Mr. G. Cumberland of Bristol has recommended the making of large files with a compound of clay and ground silica, and, when they become sufficiently dry, to form the teeth by the pressure of muslin of various degrees of fineness; after which they are to be burnt, to bring them to the hardness of the

³ Nicholson's *Journal*, vol. xii. p. 63.

best stoneware¹. Such tools might be made much cheaper than the commonest steel files, and for many purposes that might be mentioned they would be of great utility.

In visiting a manufactory of files, I could not avoid noticing an expedient which the workmen adopt in the process of hardening that instrument, and which is, perhaps, as perfect and efficient as any they could have been directed to by the most correct knowledge of chemical science, though it was doubtless the mere result of accident and observation, without the aid of any theory whatever.

Some of the large files are very thick, and require to be submitted to an intense heat in order to give them the requisite degree of hardness; and yet the teeth of these instruments are sometimes so delicate, that the action of the fire, aided by that of the atmosphere, would, if they were unprotected, be quite sufficient to convert them at one heat to a crumbling oxide, and of course to render the tool useless. These manufacturers therefore make a mixture of common salt and powdered bone-ash with grounds or settlings of ale; and when these become of a proper consistence, each file is completely covered with it before it is thrust into the body of the fire.

When first covered with this preparation, they are laid one by one at some distance above the fire, and across some slight bars of iron fixed within the brick-work on purpose to receive them. Here they acquire a sufficient degree of heat just to bake on the mixture, and harden it so as to prevent its removal by the friction of the coals as it is put into the fire-place. When this is properly baked on, they are heated red-hot, and immediately plunged into cold water, or some other fluid, to complete the hardening process. This is done rather slowly, and at the same time care is taken to introduce them into the water in a perpendicular position, which is necessary to prevent these instruments from warping by the sudden transition. Diluted sulphuric acid was formerly employed for this purpose, it being imagined that it rendered the files harder; but this has lately been given up, and recourse is now generally had to cold water only. Reaumur recommends aquafortis for this purpose², as before mentioned; but I apprehend it is not better than cold water alone.

Though the mode just described may be perfect, the composition of the article with which the files are covered may perhaps be still improved. Thus, several artists mix some *animal* substance with the saline compound, and this is likely to be a considerable

¹ Nicholson's *Octavo Journal*, vol. xxv. p. 257.

² *L'Art de convertir le Fer en Acier*, p. 359.

improvement. On the contrary, some file-makers use common flour instead of bone-ash, and mix it with the saturated solution of salt till the whole acquires the consistence of treacle. There is an advantage in this mixture, namely, that a mere single immersion of the files in it is sufficient to coat them entirely, and perfectly protect them from oxidizement.

I had forgotten to mention, that when these instruments have been tempered in the manner already described, they are well washed in water, and then brushed with dry coke-dust, which makes them quite clean, and gives them a considerable degree of brightness.

It has been recommended to make files for some particular trades, with iron, and then to case-harden their surfaces, because such files would bend, and hence might be made useful for many purposes to which common steel files cannot well be applied. This method of preserving the teeth of files and rasps while tempering, is described, under the idea that a general knowledge of it might perhaps furnish some useful hints respecting the preservation of metals, especially iron, from oxidizement during the progress of this and other similar processes in the arts.

From these few observations the reader may conceive, that the discovery of some certain and infallible mode of imparting any specific degree of heat to iron or steel, that may be necessary for the processes of hardening and tempering, must be an important desideratum in the manufactory of edge tools.

In the year 1789 Mr. David Hartley took out a patent for a method of tempering steel by the aid of a pyrometer or thermometer applied near to the surface of the article, and at the same time recommended the use of heated oil, in which he says many dozens of razors or other tools might be tempered at once with the utmost facility, and the various degrees of heat necessary for the different purposes might speedily be determined by experiment.

When I first saw this announced in the public journals, it immediately occurred to me that the principle might be improved upon; and if a bath of oil, or of some kind of fusible metal, were contrived for the tempering of every species of edge tool, that a greater degree of certainty would be given to this operation, than the persons who have generally the conduct of such manufactories have ever experienced.

Influenced by these views of the subject, I determined long ago, that I would embrace some opportunity of instituting a series of experiments, to determine at what degrees of temperature all the common kinds of oil enter into ebullition, and also the melting points of several metallic compounds, in order to be able to furnish the practical cutler with a few tables, whence he might learn

how to construct a bath in which he could at all times impart the desired temper to the particular instruments of his manufacture, with the utmost certainty and with unusual dispatch ¹.

In the application of this principle of tempering edge tools in a fluid menstruum, whether metallic or otherwise, it will be advisable to have the bath which is to contain the heated fluid, made of cast-iron, which should vary in form and size so as to adapt it to the particular sort of tools or instruments which are to be tempered within it. And where the business is considerable, it would be convenient to have two such baths fixed in brickwork, adjoining to each other and heated by the same fire, with registers to cut off the communication of either of them with the fire-place at pleasure, so that one might be heating while the workman was tempering his goods in the other.

Many advantages would result from this method of tempering edge tools. In the first place, there could never be any uncertainty as to the degree of temper which the articles would acquire; for, when the manufacturer had once ascertained which of the metallic baths was suitable for any particular kind of edge tool, all that would be necessary would be to arrange the goods in rows upon the surface of the congealed metal, to light a fire underneath the containing vessel, and then carefully to observe when the surface of the fusible metal begins to melt. As soon as this takes place, the edge tools are immediately to be removed and plunged into cold water, by which means the whole parcel will have acquired exactly the same temper.

Secondly, where instruments have a thick back and a fine edge, it is almost impossible ever to give them an uniform temper by the old method; for there will always be a danger of the edge being lowered too much before the other parts become regularly heated throughout. This difficulty occurs particularly in razors, where the thickness of the back is always a formidable obstacle to the attainment of an uniform regularity of hardness. It may however be determined by means of nitric acid, whether a razor or other polished edge tool be of an equal degree of hardness: for, on applying this acid to bright steel, the black tinge will appear more speedily and strongly upon the hard parts than on the rest of the surface. The inconvenience attendant on the manufacture of this particular instrument has been so great, that Messrs. Rhodes and Champion, eminent cutlers of Sheffield, have invented what they call the "New frame-bladed Razor," in which the back and the finger-hold are made with an alloy of copper,

¹ These experiments were tried by Mr. Parkes, and the results given in a tabular form in the Additional Notes to the 2nd edition of these Essays in 2 vols. 8vo, but from their great length are unavoidably omitted in reprinting the work in one volume.

not subject to rust, and the blade only is made with steel. These blades being nearly as thin at the back as at the edge, they can be tempered without incurring the danger already mentioned; and when one of these is let into the copper back, it becomes a complete instrument. This however is attended with a considerable additional expense, which would be unnecessary if the plan of the metallic bath be adopted.

In the hardening of large files and rasps, which require to lie a considerable time in the fire before they become heated throughout, this expedient would be of incalculable advantage; indeed, I know of no instrument, except the scythe, and the pit-saw, which might not be tempered with more certainty by means of a fluid bath than by the process in common use. And there is no reason for excepting these but their great size, which would render the tempering of them in metallic baths both troublesome and expensive.

When the sword was the chief weapon of war, it must, as Mr. Nicholson has observed, have been an object of great interest and demand to give to its blade a durable keen edge, and a degree of firmness or strength, which, without rendering it unwieldy, should ensure the warrior against exposure to the fatal accident of its breaking in the act of combat.

Formerly, no man in Great Britain knew how to temper a sword in such a way that it would bend for the point to touch the heel and spring back again uninjured, except one Andrew Ferrara, who resided in the Highlands of Scotland. The demand which this man had for his swords was so great that he employed workmen to forge them, and spent all his own time in tempering them; and found it necessary, even in the day-time, to work in a dark cellar, that he might be better able to observe the progress of the heat, and that the darkness of his workshop might favour him in the nicety of the operation. Had this ingenious artist thought of a bath of oil, he might have heated this by means of a furnace underneath it, and by the use of a thermometer, to the exact point which he found necessary; though it is inconvenient to have to employ a thermometer for every distinct operation. Or, if he had been in possession of a proper bath of fusible metal, he would have attained the necessary certainty in his process, and need not have immured himself in a subterranean apartment.

The swords which were formerly in the highest repute, were made at Damascus in Syria. The method by which these were made, has long been lost; or perhaps it was never thoroughly known to Europeans; but it is supposed that they were formed by alternate layers of extremely thin plates of iron and steel bound together with iron-wire, and then firmly cemented together by welding. These weapons never broke, even in the hardest con-

flict, and yet they retained so powerful an edge, that the armour made like net-work with scales of iron, or with small iron rings, called coats of mail, was instantly divided under their force.

This manufactory at Damascus had formerly the greatest reputation throughout Europe and through a great part of Asia; but in the latter end of the fourteenth, or at the beginning of the fifteenth century, Timour Bec, usually called Tamerlane, on his conquest of Syria¹, carried away all the best workers in steel from Damascus to Persia; and we know so little of Persia, that it may be difficult now to ascertain whether this peculiar manufactory is still carried on in that country, or not.

A writer in Nicholson's Journal, who had the opportunity of examining a real Damascus blade, which had cost the possessor twelve guineas at Constantinople, has thus described it: "It had (says he) a dull grey or blueish appearance, was scarcely harder than common steel from the forge, was not easily bended, and when bended had no spring to recover its figure. Its back was smooth, as were also two narrow sloped surfaces which formed its edge under an angle of about 40 degrees; but its flat sides were every where covered with minute waving lines in masses in all directions, not crossing each other, and, for the most part, running in the direction of its length. The lines were in general as fine as harpsichord wire, not extremely well defined nor continued; and their distinction from each other was effected by no perceptible indentation of the surface, but rather by the succession of parts differing in the degree of polish or brightness."

"I was informed," says the writer of the memoir, "that if any part of this blade were made smooth by grinding or whetting, the wavy appearance, called the water, could be again produced by means of lemon juice; and that its excellencies were, that it could be depended upon not to break; and that it would cut deeper into a soft substance, such as a pack of wool, or into flesh, than any other kind of sword blade."

"I infer therefore," adds the writer, "that the Damascus steel is in fact a mechanical mixture of steel and iron; that it is incapable of any considerable degree of hardness, and consequently is in no danger of breaking from its brittleness; that its tenacity is ensured not only from the admixture of iron, but likewise from the facility with which its soundness may be ascertained throughout, by the same process which exhibits the water or fibrous appearance; and, lastly, that the edge of a weapon formed of this material must be rough, on account of the different resistance which the two substances afford to the grindstone, in consequence of which it will operate as a saw, and more readily cut through

¹ Gibbon's *History of the Decline and Fall of the Roman Empire*, 8vo, vol. xii. pp. 21 and 45.

yielding substances than such cutting tools as are formed of a more uniform substance." Vol. i. p. 468—471.

The conjectures of this writer respecting the methods by which these blades were manufactured at Damascus, and the account of the experiments which he himself undertook for the purpose of enabling him to imitate them, are extremely interesting and instructive, so much so that I have no hesitation in recommending the whole paper to the perusal of all those who are curious in the manufacture of edge tools.

I have some other observations to make before I conclude this Essay. "It is a generally prevailing opinion," says Mr. Rhodes, "amongst men accustomed to the process of hardening steel, that if it be overheated previously to immersion, an extra portion of heat is likewise required to reduce it, or what is termed *let it down*, to a proper degree of hardness; and that without this a good cutting edge cannot possibly be produced. This, indeed, to say the least of it, is a miserable and ineffectual attempt to remedy one error by the introduction of another. That this is an extremely injurious opinion, and that it operates perhaps more than any other cause whatever, to produce a mass of inferior cutlery, must be obvious to every one who thinks at all upon the subject.

"It may be laid down as a position, which is not in much danger of being controverted, that *the lowest possible heat at which steel becomes hard is indubitably the best*; and that to impart to it any extra portion, is essentially to affect its most valuable properties. If over-heated, the pores of steel become open and expanded, the fineness of its texture is annihilated, and it is rendered so extremely susceptible of injury from the influence of heat, that a small portion acting upon it, when it is in this state, entirely destroys its capability of sustaining a cutting edge.

"It must not be inferred from these remarks, that any degree of temper whatever will operate to restore to steel the pure properties of which it has been deprived by being over-heated. Workmen, however, acting under the influence of the preposterous opinion here deprecated, manifest great carelessness in the performance of this very critical operation, always imagining the evil effects of this carelessness may be remedied by resorting to a practice most palpably erroneous²."

From the information which I have collected in various quarters, I am inclined to think that the bad temper of many of our small edge tools may be attributed to improper management in tilting

² An Essay on the Manufacture of a Razor. By E. Rhodes, Sheffield, octavo, 1809, p. 18.

the steel ; I therefore, on a late journey to the north of England, embraced that opportunity of visiting the public forge which is employed by most of the cutlers in the town of Sheffield, and where these manufacturers send their steel to be drawn out into bars of different forms and of different sizes, according to the various purposes for which it is intended. I observed that the process of tilting, or drawing out into fine bars, is conducted in the following manner.

The steel, which is usually in bars of $2\frac{1}{2}$ inches square and about $2\frac{1}{2}$ feet long, is put, several bars together, into a wind furnace, that it may be sufficiently softened by heat to render it quite ductile under the forge-hammer. This hammer, which is very weighty, is moved by a water-wheel, and strikes incessantly upon an anvil fixed immediately beneath it. By means of this apparatus the heated bars may be drawn down to any size which the manufacturer requires ; and one man and a boy are all the hands which are necessary for performing the work.

To conduct this operation the man seats himself in a *hanging* wooden seat, very similar in appearance to one of the wooden planks suspended to a pair of large scales, and which is fixed to the ceiling by four strong iron wires, in such a position as to swing directly opposite to the anvil on which the steel is to be laid and drawn into bars.

When the man has properly fixed himself in this seat, the boy brings him one of the heated bars and slides it under the forge-hammer. The workman immediately takes charge of it, and moves it a little either backwards or forwards according to his judgement, every time the hammer rises, so that every part of the metal in its turn may be uniformly submitted to the action of the forge-hammer. By this repeated hammering the steel is soon drawn very considerably thinner ; and when the workman finds that it is becoming too cold for the forging to make the proper impression upon it, it is once more or oftener heated in the furnace, and as often submitted to the action of the tilting hammer, until it be reduced to the desired size and shape.

As only one extremity of the bar is at first submitted to the action of the hammer, and as it is necessary to slide it gradually further and further underneath it, the workman is under the necessity of approaching nearer to the anvil or of receding from it, every time the hammer rises or falls. To enable him therefore to do this with facility, there is a small well of about a foot deep, sunk within the floor for the reception of his legs, and directly under that part of the ceiling to which his seat is suspended. Things being thus arranged, the operator is enabled by a slight motion of his foot, and without any painful exertion, to move himself either backwards or forwards as his work requires.

While I attended this operation, I observed that very different degrees of heat were given to the strong bars in order to soften them for the tilt-hammer ; and I can readily conceive that the injury which I have spoken of as being done to bar-steel at the tilting-house, may be entirely attributed to this circumstance—the unequal or superfluous application of heat.

I observed, also, that those bars which were unnecessarily heated, threw off a prodigious number of thin scales at every blow of the hammer ; and when I made inquiry respecting this, I was informed that the manufacturers generally expect that the steel which they send to this establishment will lose five per cent. in weight by the operation of tilting ; and that when the bars are heated more than necessary, this loss is always proportionably greater. The charge usually made for drawing steel into fine bars, is from 5*s.* to 6*s.* 6*d.* per cwt. according to the size required.

After I had visited this public forge and witnessed the carelessness with which the bar-steel is heated, I felt extremely desirous of ascertaining the degree of effect produced on cast-steel by being brought to too high a temperature, not doubting that the badness of many of our edge tools might be chiefly ascribed to this cause. Therefore, before I left Sheffield, I procured a small bar of cast-steel, and having borrowed the use of a hearth, I made the following experiment.

The bar of steel was first broken into three pretty equal parts ; I then heated one of these to a low red heat, and immediately cooled it by sinking it very gradually into a trough of cold water. The second was heated considerably more, even to a full red, and cooled in the same manner. The third was brought to an intense white heat, and then instantly quenched in cold water, like the preceding parts.

Afterwards, on breaking a small piece from one end of each of these bars, the following appearances presented themselves, which completely satisfied me of the decisive nature of the experiment. The first exhibited a very fine, close, and compact grain ; the second was of a much coarser texture ; and the grain of the third was analogous in all respects, and quite as coarse as that of a piece of common cast-iron.

It is well known that cast-steel is brittle and useless before it be tilted, or drawn out by the forge-hammer ; but if it be heated too much for this operation, the texture of the metal will be so much altered by this excess that it will be rendered entirely unfit for the fabrication of fine instruments. It may here however be mentioned, that such steel as will suit one implement is often not fit for another. That which has the most blisters is generally the hardest and fittest for files, &c. ; but the softest steel, or that

which approaches the nearest to the state of wrought-iron, is most suitable for many other purposes.

There is another circumstance which militates very much against the perfection of the finer sort of edge tools, namely, the velocity that is given to the motion of the stones on which the instruments are usually ground and polished. The workmen at Sheffield are not paid for their time, but by the piece, or according to the quantity of work finished; it is consequently their interest to use the utmost dispatch, and urge the grinding-stones to the most rapid motion, because the amount of the work will, in fact, be in proportion to the celerity of the revolving stones.

At Sheffield the stones are usually moved either by a steam-engine or a powerful water-wheel; therefore any degree of velocity may be given to them, by simply moving the strap to a pulley of a larger or smaller diameter. This indeed has sometimes been pushed to such an extent, that the stones, merely by the centrifugal force which they had thus acquired, have been dashed into innumerable pieces, and have occasioned the death of the workmen and bystanders.

Those who have paid attention to the process of tempering steel will readily conceive the great injury that a fine edge tool is likely to suffer from the accumulated heat occasioned by a revolving grindstone, or other rough mineral substance in rapid motion. This is an evil of great magnitude; but unless men of real principle be found who would willingly engage in this employment, and be content that their own interests should be subservient to that of their master, and that their first aim be to give perfection to the quality of the goods they fabricate, I am afraid that no effectual remedy can be adopted.

In a late voluminous but very respectable publication it is said, that the *Wickersley* stone is usually employed for grinding edge tools, because this stone has the peculiar property of not heating to a great degree any substance ground upon it. This appeared to me to be so very extraordinary that I determined to make an inquiry, on my next journey into Yorkshire, respecting this circumstance. I have since however been assured by some of the most extensive cutlers at Sheffield, that the assertion is without foundation, and that there are other reasons for the preference which is often given to this particular stone.

Wickersley is a village situated between Rotherham and Doncaster, about ten miles north-east of Sheffield. From the inquiries which I have made, I learn that this stone, which is of a light-buff colour, with a slight shade of red intermingled, is used for grinding all the fine hard steel goods, such as razors, penknives, and the best

scissars ; and it is preferred for these, not because it produces a less degree of heat in the operation, but from the fineness of its texture, from the rapidity with which it cuts, and from its not being subject to have hard or knotty places interspersed in it, an imperfection to which most other grindstones are liable. The workmen in general give the preference to these stones for articles made with hard steel ; but soft or unhardened goods, such as fork-shanks, for example, are usually ground with a stone which possesses a much greater degree of hardness.

In the Supplement to the *Encyclopædia Britannica*, article CUTLERY, mention is made of a green stone found in some parts of the old pavement of London, as the only known material capable of giving to lancets the smooth edge which they require. This stone, which is now extremely rare and valuable, is a soft hornstone. Its analysis has been published by Mr. Faraday.—*Quarterly Journal*, vol. vii. p. 400.

Another kind of edge tool remains to be described, which is made of *cast-iron* and afterwards converted into steel. The method of conducting this process was discovered by Mr. S. Lucas of Sheffield, and he has obtained a patent for the invention. In order that all classes of readers may be able to appreciate the merits of this very ingenious process, it will be necessary to explain what constitutes the difference in the various sorts of iron, and likewise in what respect this differs from steel.

Iron is found in the state of an ore in the bowels of the earth, and, in abstracting from this an useful metal, the first product is generally *cast-iron*, which owes its fusibility to the combination of carbon. This varies, however, in quality according to the quantity of carbon combined with it ; and consequently such kinds are selected as are thought to suit the different purposes to which they are to be applied. That which contains the most carbon is chosen for small castings and for the neater kinds of ornamental work, while the harder metal, which has less carbon, is always preferred for railways, water-wheels, and all other large articles which are designed to sustain much wear.

It is necessary that the carbon be intimately united with the metal to form good pig-iron. This accounts for the preference which is always given to that iron which is made with wood-charcoal, for this enters more readily into combination with the iron than even the best mineral coke. When coke is employed in the process of making pig-iron, that which is the softest is always found to be the best, while the *hard* coke is selected for heating the blast furnaces.

Wrought-iron is malleable though very infusible, and it acquires these changes in its properties by continued heat and repeated

hammering, which deprive the metal in a great measure of the carbon which occasioned its great fusibility when in the state of cast-iron. But it varies very much in its quality, according to the mode of its preparation, and the nature of the coke or charcoal which has been employed in its manufacture.

Steel differs from wrought- as well as from cast-iron, in having resumed a small portion of carbon, and likewise by containing a very minute proportion of silica and phosphorus. Steel is a most important preparation of iron; for it possesses the malleability of wrought-iron without its infusibility, and also has the fusibility of cast-iron without the brittleness of that substance. It completely unites the malleability of the one with the fusibility of the other. A particular account of the methods by which steel was usually prepared in the middle of the last century is given by Mr. Dossie in his *Institutes*¹. Some account of the present modes of making both the blistered and the shear steel has already been given. Cast-steel, according to Mr. Aikin, is made by the following process:—

“The finest kind of steel, called *English cast steel*, is commonly prepared,” says he, “by breaking to pieces the blistered steel, and then melting it in a crucible with a flux composed of carbonaceous and vitrifiable ingredients. The vitrifiable part of the mixture is of use only in as much as it is a fusible body, which flows over the surface of the metal in the crucibles, and prevents the access of the oxygen of the atmosphere. Broken glass is sometimes used for this purpose.

“When the metal is thoroughly fused, it is cast into ingots, which by gentle heating and careful hammering are tilted into bars. By this process the steel becomes more highly carbonized in proportion to the quantity of flux, and in consequence is more brittle and fusible than before. Hence it surpasses all other steel in uniformity of texture, hardness, and closeness of grain, and is the material employed in all the finest articles of English cutlery².”

In the year 1820, Oostad Muhammed Ali described in the Laboratory of the Royal Institution of Great Britain the method of making cast-steel in Persia. The iron, he said, is brought from the mountains: a square place is built up, about four feet in the side, and five or six feet high, the walls eight or nine inches thick; stones of a slaty kind are placed in the inside about 18 inches from the bottom, so as to form a grate; below this is a chamber for the reception of the melted steel, and above it is placed the iron in bars, and charcoal intermingled together.

¹ Dossie's *Institutes of Experimental Chemistry*, vol. ii. p. 375—388.

² Aikin's *Chemical Dictionary*, article *Iron*, vol. i. p. 602.

There are three apertures above the grate into the furnace, into which air is propelled from bellows worked by men sitting ; a fire is lighted, and the heat raised ; fresh charcoal is thrown on as that in the furnace burns away ; and as the iron becomes carbonized, it melts and falls through the grate as fluid cast-steel, into the chamber beneath, whence it is taken and cast into ingots.

To prepare the cast-steel, three or four hundred weight of iron is placed in such a furnace, and there is a loss of about one-third from oxidation, and adhesion to the sides. The operation requires from two to three days, with constant blowing. M. Muhammed described the charcoal that was employed, as being exceedingly hard and heavy, and very unlike our charcoal, but did not know of what wood it was made.—*Quarterly Journal*, vol. viii. p. 160.

The invention by Mr. Lucas, of converting edge tools made of cast-iron into good steel, appears to be an important improvement. It consists in stratifying the cast articles, in cylindrical metallic vessels, with native oxide of iron pulverized, or sand containing oxide of iron, and then submitting the whole to a regular heat in a furnace built for the purpose. It is not necessary that the oxide employed should be a *native* oxide, any artificial oxide being equally effective ; that kind which can be had cheapest is therefore generally preferred. The operation may be thus explained :—

The cast-iron, of which this cutlery is made, is brittle in the first instance, like other cast-iron, in consequence of the carbon contained in it ; but the great heat which it undergoes, aided by the pulverized oxide, separates the carbon : this uniting with the oxygen of the ground oxide of iron, is dissipated in the state either of carbonic oxide or carbonic acid gas, and the goods are then converted into a state very similar to that of good cast-steel cutlery.

To prevent misconception, it may be necessary to state, that cast-iron which contains a *large* proportion of carbon is less brittle than that which is combined with a smaller quantity. It can also be filed and cut with a cold chisel, while the latter, although it may be more readily broken, effectually resists the action both of the chisel and the file. In conformity with these facts, small machinery made of common cast-iron may be softened merely by cementation with a carbonaceous substance, thereby augmenting its dose of carbon, and rendering it capable of being smoothed by the file.

I understand that the best pig-iron is always chosen for making the various articles of cutlery, while the poorest iron ore, if free from sulphur, may be pulverized and stratified with them to afford oxygen.

After several years experience, Mr. Thomas Lucas has been enabled to bring this process to such a state of perfection, that his cast cutlery will bear a polish equally brilliant with the best cast-steel goods, as I can testify from my own observation; and will also take as fine an edge, so that some of the best judges of cutlery cannot distinguish the difference. When, however, the cast cutlery wares which have been thus annealed, are submitted to the usual processes of hardening and tempering, they are apt to be more brittle than those edge tools which are made in the usual way with the best steel.

It has also been found that by varying the process small pig-iron castings can be converted into good malleable iron: in consequence of this the patentee now makes a great variety of small iron utensils by *casting*, which were formerly made only on the anvil of the blacksmith; and when he has converted the metal to the quality of soft malleable iron, these articles are found to be equally fit for a great variety of purposes, and can be afforded at a much lower rate than similar goods which have been modelled by hand, as heretofore. He has become so complete a master of this business, that he can convert cast-iron goods either into the state of wrought-iron or steel at pleasure.

Mr. Lucas has shown me articles made with pig-iron which appeared perfectly malleable. I have seen cast nails which would bend like common wrought-iron nails, and small articles that would bear even to be welded together by the usual process.

In conducting these operations, he has sometimes observed that when dark or highly carburetted cast-iron is fused in small quantities, plumbago is separated, and the metal, by thus losing a part of its carbon, becomes white. Here a question occurs;—Why did not the plumbago separate on the first cooling? Is it not probable that crude iron combined with a certain portion of carbon, is thereby rendered capable of dissolving and retaining in combination a quantity of plumbago, in the same manner as water saturated with carbonic acid, will dissolve an extra portion of carbonate of lime?

I have also to observe, that the steel which the patentee makes by the process of cementation, possesses, in common with that manufactured in the usual way, the susceptibility of being powerfully magnetized, and appears to retain the magnetic property as well as other steel. He has indeed in his possession a small instrument in the form of a horse-shoe magnet, made with *cast-iron*, and afterwards converted by his peculiar process to steel, which he has had magnetized, and it is now capable of sustaining by its magnetic power, a weight nearly equal to three pounds.

I have only to add that Mr. Lucas has very obligingly furnished me with a drawing of the furnace which he employs in

these processes, and, with his permission, I have had a copper-plate engraving of it made to accompany this Essay.

Since the publication of the first edition of these Essays, Messrs. Stodart and Faraday have undertaken a series of very important experiments on the alloys of iron and steel, with various other metals; the object of which was, first to ascertain whether any alloy could be artificially formed, better for the purpose of making cutting instruments than steel in its purest state; and, secondly, whether any such alloys would, under similar circumstances, prove less susceptible of oxidation. An account of these experiments having been given in considerable detail, both in the *Philosophical Transactions*, and in the *Quarterly Journal of Science*, I trust that a careful abridgement of all the papers on this subject, or at least a transcript of the most important results of the several experiments, will be useful and highly acceptable to the public.

These experimentalists found that by combining a very small portion of alumina with good steel, an artificial *wootz* was produced, which, when the surface was polished, gave, on the application of dilute sulphuric acid, the beautiful damask appearance which has hitherto peculiarly belonged to the Asiatic steel. It is remarkable that the *wootz*, although repeatedly fused, retains the peculiar property of presenting a damasked surface, when forged, polished, and acted upon by dilute acid.

“Platinum, rhodium, gold, silver, nickel, copper, and tin, were alloyed with both English and Indian steel, and in various proportions. All these metals have an affinity for steel sufficiently strong to make them combine; and this is so remarkable with platinum, that it will fuse when in contact with steel, at a heat at which the steel itself is not affected.

“When one part of silver to 500 parts of steel were properly fused, a very perfect button was produced. The specimen forged remarkably well, although very hard. By a delicate test every part of the bar gave silver. This alloy, they say, is decidedly superior to the very best steel, and this excellence is unquestionably owing to combination with a minute portion of silver. It has been repeatedly made, and always with equal success. Various cutting tools have been made from it of the best quality. This alloy is perhaps only inferior to that of steel with rhodium, and it may be procured at a small expense; the value of silver where the proportion is so small, is not worth naming; it will probably be applied to many important purposes in the arts.

“The alloys of steel with platinum, when both are in a state of fusion, are very perfect, in every proportion that has been tried. Equal parts by weight form a beautiful alloy, which takes a fine

polish, and does not tarnish; the colour is the finest imaginable for a mirror. The specific gravity of this beautiful compound is 9.862.

“The proportions of platinum that appear to improve steel for edge instruments are from 1 to 3 per cent.; 1.5 per cent. will probably be very nearly right.

“The alloys of steel with rhodium are likely to prove highly valuable. The scarcity of that metal must, however, operate against its introduction to any great extent. This alloy was made at the suggestion of Dr. Wollaston. The proportions of rhodium used, were from 1 to 2 per cent. The valuable properties of the rhodium alloys are hardness, and sufficient tenacity to prevent cracking either in forging or in hardening. This superior hardness is so remarkable, that in tempering a few cutting articles made from the alloy, they required to be heated full 30° of Fahrenheit higher than the best wootz, wootz itself requiring to be heated full 40° above the best English cast-steel. Thermometrical degrees are named, that being the only accurate method of tempering steel.”

“Gold forms a good alloy with steel. Experience does not yet enable us,” say they, “to speak of its properties. It certainly does not promise to be of the same value as the alloys of silver, platinum and rhodium.”

The authors conclude this valuable paper¹, by observing that, “from the facility of obtaining silver, it is probable that its alloy with steel is the most valuable of those we have made. To enumerate its applications would be to name almost every edge tool. It is also probable that it will prove valuable for making dies, especially when combined with the best Indian steel.”

In a subsequent paper² these experimentalists give an account of the manufacture of the alloys upon a larger scale. In these experiments they discovered, with regard to the silver alloy, that “steel will only retain one 500th part in union; when more was used, it either evaporated, or separated as the button cooled, or was forced out in forging. The alloy was excellent, and the trifling addition of price furnishes no obstacle to its general employment.”

“Steel alloyed with the 100th part of platinum, though not so hard as the silver alloy, has more toughness; hence its value, where tenacity as well as hardness is required: the extra cost is more than repaid by its excellence.

“The action of acids on these alloys is curious, and especially in respect to that of platinum, which is acted upon by diluted

¹ *Quarterly Journal of Science*, vol. ix. p. 319—330.

² *Philosophical Transactions* for the year 1822, part ii. p. 253—270.

sulphuric acid with infinitely greater rapidity than the unalloyed steel ; indeed, an acid that scarcely touches the pure steel, dissolves the alloy with energetic effervescence. This is probably referable to electrical excitation."

It is remarkable that when pure iron is substituted for steel, the alloys so formed are much less subject to oxidation. Three per cent. of iridium and osmium, fused with some pure iron, gave a button, which, when forged and polished, was exposed, with many other pieces of iron, steel and alloys, to a moist atmosphere; it was the last of all showing any rust. The colour of this compound was a distinct blue.

Dr. Brewster states that Mr. Stodart favoured him with specimens of several of these alloys for optical purposes ; and though various plates of polished steel kept beside them for more than a year, were all affected with rust, yet not one of the alloys had suffered the least change³.

When the public had been informed of the success which had attended the experiments of Messrs. Stodart and Faraday, M. Berthier was induced to try the effect to be obtained by adding a portion of chromium to steel. "Two alloys of cast-steel and chromium were made, one with 0.01, the other with 0.015 of chromium. These, he says, both forged well, the first better than cast-steel. A knife and a razor were made from them, and both proved very good; their edges were hard and solid, but their most remarkable character was the fine damask they took, when washed over with sulphuric acid. This damask was composed of white silvery veins, and nearly resembled that given by the alloy of steel and silver. The white parts are probably pure chromium, on which acids have no action. This chromic steel was prepared by fusing together cast-steel and the alloy of chromium and iron⁴."

³ The *Edinburgh Philosophical Journal*, vol. vii. p. 350.

⁴ *Quarterly Journal of Science*, vol. xii. p. 174. *Annales de Chimie et de Physique*, tome xvii. p. 55.

ESSAY XVI.

ON THE MANUFACTURE OF TIN-PLATE.

[First printed in the MEMOIRS OF THE LITERARY AND PHILOSOPHICAL SOCIETY OF MANCHESTER, Vol. III. New Series; and copied from thence into the *Annales de Chimie et de Physique*, tome xii. for the year 1819, p. 153.]

As the processes in this manufacture are more numerous and complicated than they are generally imagined, it may be advisable to preface the account with an enumeration of some of those properties of tin which will be most likely to explain the rationale of the principal operations.

Tin has a great affinity for several of the other metals—particularly for zinc, mercury, copper, antimony, lead and iron; and owing to these affinities, its employment in the arts is very considerable.

Tin, with zinc, forms a metal of close grain, very useful for many purposes, especially for the formation of *pewter*. The zinc is found to impart great hardness to the tin, without lessening its ductility.

The combination of mercury and tin, in which the tin is dissolved by the mercury into a very soft amalgam, is largely employed, as is well known, in silvering the backs of mirrors, and for other purposes in the arts. An amalgam of tin of greater consistence was formerly in use in the museums of Paris for closing the mouths of glass-bottles containing sundry curious and valuable preparations.

Copper is also alloyed with tin for various purposes of manufacture. This metallic mixture is employed in making what are called bronze statues; for casting bells, and pieces of artillery, and also for the fabrication of medals and medallions. In some of these cases the tin is mixed with copper, on account of its property of rendering the copper more fusible; and this was probably the reason why the ancient Romans used that metal in the greater part of their brass coinage. It is owing to the affinity of tin for copper, that vessels of capacity, made with the latter metal, for culinary and other purposes, are so readily covered with a coating of tin, to preserve them from the action of substances

which would not fail to erode copper, if unprotected by some such covering. The affinity of tin for copper is further exemplified by the process of whitening *pins*, which is effected by boiling the pins with granulated tin in a lye made with alum and tartar¹.

An useful alloy is likewise formed by the mixture of tin and antimony. This metallic compound is very white, extremely hard, and will bear a very fine polish. On these accounts it is employed in making specula for telescopes, and also for the manufacture of rolled plates to engrave music upon.

The next metal which I have mentioned as uniting readily with tin, is lead. This metal will combine with tin in any proportion; and in most proportions the lead acquires a greater degree of fusibility by its union with the tin. It is this alloy which forms plumbers' solder; but that compound is prepared with different proportions of tin, according to the purpose for which it is intended. The article called tin-foil, used for lining tea-caddies, for coating electrical jars, and for other purposes, is also made from a mixture of these two metals.

But what is more relevant to the subject of this paper is the chemical affinity which subsists between *tin* and *iron*. One of the strongest proofs of this affinity is derived from the circumstance that even *cast-iron* may be tinned in the same manner as wrought-iron. Of late years, cast-iron saucepans, and pots of a large size, are permanently tinned on their inner surfaces, to prevent the liquors which are boiled in them from acquiring any stain by a partial dissolution of the iron. Many other articles, such as bridle-bits, common stirrups, small nails, &c. are now made much cheaper than formerly, by first fabricating them in cast-iron, and then covering them with a thin coat of tin, by the immersion of them in a hot mass of that metal in a state of fluidity.

That these effects are owing to chemical affinity, cannot be doubted, when it is considered, that in all these cases the pores of the iron are in some degree actually penetrated by the tin.

In the manufacture of *tin-plate*, which I am now about to describe, a similar effect is produced, and also by the same means. Plates of iron properly prepared, are immersed in a large mass of melted tin, which is kept hot by a fire constantly burning underneath it;—the consequence of which is, that the tin in some measure penetrates the iron, and this attaches other tin to it, so that the whole surface of the iron acquires, by this means, a complete covering of that metal.

As no accurate account has ever yet been given of the various

¹ An interesting Memoir (by M. Gadolin) on the Tinning of common Pins, will be found in the *Journal de Physique*, 1789.

processes by which this is effected, the following outline may probably be acceptable to the public.

English bar-iron of the finest quality, called tin-iron, and which is generally prepared with *charcoal* instead of mineral coke, and made with the greatest care, for this particular purpose, is first cut to the necessary length, and then rolled at the mill, between a pair of cast-iron rollers of about 17 inches long and 12 or 13 in diameter, into plates of the requisite thinness, and of such form as is suitable for the business. These plates are then cut by hand-shears to the sizes suitable for the different markets¹. And as the shearer shears the plates, he piles them in heaps, occasionally putting one plate the cross way, to keep each box separate. Two hundred and twenty-five plates are called a box; but they are not put into boxes of wood in this stage of the operation. The iron plates now go into the hands of the *scaler*, who takes them from the shear-house, and bends each of them singly across the middle, into this form Δ , preparatory to their being cleaned for tinning, and for the conveniency of putting them into the scaling furnace, as will be more fully explained hereafter.

This furnace, or oven, is heated by *flame* thrown into it from a fire-place of a peculiar construction; and it is this flame that scales the plates, which are put into the oven in rows, and arranged three in each row, until the oven is full. It will be obvious that if they lay flat on the floor of the oven, the flame could play only on one side of each plate, whereas by being bent in the form already described, the flame can operate equally on both sides. It may here be remarked that the form of all tin-plates, one sort excepted, is that of a parallelogram, and that if a piece of stiff paper or pasteboard, $13\frac{3}{4}$ inches long, and 10 inches wide, be bent in the centre at an angle of about sixty degrees, and then put to stand on the two ends, we shall have the form of a plate No. 1. properly bent for the scaling oven.

The operation of *cleansing*, as it is called, and which is preparatory to the process of scaling, is commenced by steeping the plates for the space of four or five minutes in a mixture of muriatic acid and water, in the proportion of four pounds of acid to three gallons of water. This quantity of the diluted acid will generally be sufficient for eighteen hundred plates, or eight boxes of 225 plates each.

When the plates have been steeped for the time prescribed, they are taken out of the liquor, and placed upon the floor, three

¹ These plates are generally cut *by hand*; but an ingenious whitesmith in Glamorganshire a few years ago invented a method of shearing them by a *machine*. This machine is worked by a water-wheel, and will shear 100 boxes per day; whereas a hand-shearer cannot complete more than 25 boxes in the same period of time.

in a row, and then by means of an iron rod put under them, they are conveyed to a furnace heated red-hot, where they remain until the heat takes off the scale, the removal of which was the object in submitting them to that high temperature.

When this is effected, the plates are taken to a floor, where they are suffered to cool; they are then straightened, and beaten smooth upon a cast-iron block. The workman knows by the appearance of the plates during this operation, whether they have been well scaled; for if they have, that is, if the rust or oxide which was attached to the iron has been properly removed, they will appear mottled with blue and white, something like marbled paper. The operation that we have now been describing is called *scaling*.

As it is impossible the plates can go through this process without being in some measure warped, or otherwise disfigured; they are now rolled a *second* time, in their cold state, between a pair of cast-iron rollers properly hardened and finely polished. This operation makes both sides of the plates perfectly smooth, and imparts a sort of polish to their surfaces. These *cold* rollers are each about 22 inches long, and 17 or 18 inches in diameter.

The technical name of this apparatus is *rolls*, not *rollers*. All the rolls which are employed in rolling plates, either hot or cold, in this manufactory, are *hard* rolls; and there is as much difference between a pair of *hard* cast-iron rolls, and a pair of *soft* rolls, although they may both be run out of the same pot of metal, as there is between iron and steel. The workmen inform me that the difference is entirely occasioned by the manner of casting them,—the soft rolls being cast in sand, whereas the hard rolls are formed by pouring the metal into a thick cast-iron box,—and that the metal, by coming in contact with the cold box is sufficiently chilled to render the whole face of the roll entirely hard. The difference in the temper of these two kinds of rolls is so great, that when they are put into the lathe to be turned perfectly true, the turnings from the one will be $\frac{1}{8}$ th of an inch in thickness, whilst the turnings which come from the other are not larger than very fine needles. The temper of cast-iron thus varying according to the nature of the mould into which it is poured, is a circumstance that appears to me to be deserving of attention in the manufacture of a variety of other utensils employed in the arts².

² The art of making good hard rolls appears to be very imperfectly understood, because the difficulty of producing them is very great. Not one in three can be called thoroughly good. For, if they are not sufficiently hardened on the surface, they will not wear; whereas, if they are made hard throughout, or *struck hard to the centre*, as the workmen call it, they will generally crack across the middle and become useless. This fault is quite independent of air bubbles or flaws, which are always discoverable in turning by the lathe.

These rollers are used without heat; but they are screwed down very close one upon the other, only leaving bare room for the plates to pass, that the utmost attainable degree of pressure may be given to them. This last operation is called **COLD ROLLING**.

When the plates have undergone this process, they are put one by one into troughs filled with a liquid preparation called *the lyes*.

This is merely water in which bran has been steeped for nine or ten days until it has acquired a sufficient acidity for the purpose. The design of putting the plates into the troughs *singly*, is, that there may be more certainty of the liquor getting between them, and both the sides of every plate being soaked alike in the lyes. In this liquor they remain for ten or twelve hours standing on the edges; but they are turned, or inverted, once during that time. This operation is called *working* in the lyes.

The next operation is that of steeping in a mixture of sulphuric acid and water, in proportions which vary according to the judgement of the workmen.

The trough in which this operation is conducted, is made with thick lead, and the interior is divided by partitions of lead. Each of these divisions is by the workmen called *a hole*, and each of them will contain about one box of plates. In the diluted sulphuric acid which is in the different compartments of this vessel, the plates are agitated for about an hour, or until they have become perfectly bright, and entirely free from the black spots which are always upon them when they are first immersed in it.

Some nicety however is required in this operation; for, if they remain too long in the acid, they will become stained, or blistered by it, as the workmen term it; but practice enables a careful operator to judge of the time when they ought to be removed. This, however, is one of the most difficult parts of the business, as few men like to work in it; though I understand that a good pickler is highly valued by his employers, and obtains great wages. It is necessary to notify that this, and the former process with the acidulated water, are both hastened by giving to those menstrua an increase of temperature; and this is effected by means of heated flues which run under each trough. Little additional heat is necessary in summer, however, as 90° or 100° of Fahrenheit is a temperature sufficiently high for either of these operations.

When the plates come out of the pickle, they are put into pure water, and scoured in it with hemp and sand, to remove any remaining oxide, or rust of iron that may be still attached to them; for, wherever there is a particle of rust or even *dust* upon them, there the tin will not fix; and they are then put into fresh water, to be there preserved for the process of tinning. The design of putting the plates into pure water, after they come out of the

sours, is to prevent their becoming again oxidized; for it has been found that after these operations they will acquire no rust, although they should be kept twelve months immersed in water.

It will be perceived that all these processes are nothing more than preparatory measures for the operation which is to succeed, viz. that of **TINNING**.

For this purpose an iron pot is nearly filled with a mixture of *block* and *grain* tin, in a melted state; and a quantity of tallow or grease, sufficient, when melted, to cover the fluid metal to the thickness of four inches, is put to it. However, as some persons may not be acquainted with the difference between *block* and *grain* tin, it may be remarked, before we proceed, that the metal known in commerce by the name of block tin, is prepared either from the mineral called *tin-stone*, or the one known in Cornwall by the name of *tin-pyrites*, whilst the article called *grain tin* is smelted from an ore which is found in grains, called *stream tin* ore, under beds of alluvial soil, in low situations, whither in the course of ages it has been washed from the hills by a succession of torrents of rain. The former, which is produced in the greatest abundance, is always contaminated with a portion of iron, sulphur, and other injurious substances, and is therefore only employed for common purposes; while the grain tin, which is nearly free from every impurity, and usually from twenty to thirty shillings per hundred weight dearer, is used in many processes of dyeing, and in all other cases where *pure* tin is required. I am also desirous of remarking, that in my opinion it would be more profitable to the proprietor of a tin-plate work, if he were to use *grain* tin alone, or grain tin mixed with that kind which is known by the name of "Refined Tin," because these kinds not only contain less dross, but they melt, as I know by my own experience, into a more fluid metal; and consequently, more would run off the plates in the operation of tinning, and less tin would be consumed. At present these manufacturers use the block and grain tin, in equal proportions.

When the tin-pot has been charged in the way above mentioned, the metal is heated from a fire-place underneath it, and by flues which go round the pot, until it is as hot as it can be made without actually inflaming the grease which swims upon its surface. The use of the grease is to preserve the tin from the action of the atmosphere, and consequently to prevent it from oxidizing. By melting a little tin or lead in an iron ladle, and, when the dross is skimmed off, putting a morsel of tallow upon the metallic fluid, the effect of the tallow in cleansing the face of the metal will be evident. The workmen also say, that it increases the affinity of the iron for the tin, or, as they express it, that it makes the iron plates take the tin better.

It is curious that *burnt grease*, or any kind of empyreumatic fat, effects this purpose better than pure fresh tallow.

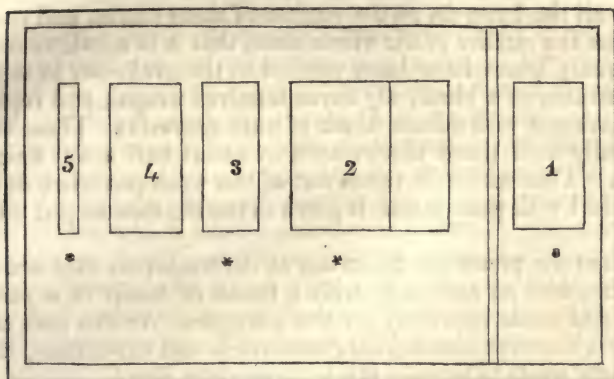
Another pot, which is fixed by the side of the tin-pot, is filled with grease only; and in this the prepared plates are immersed, one by one, before they are treated with the tin; and when the pot is filled with them, they are suffered to remain in it so long as the superintendant thinks necessary. If they remain in the grease an hour, they are found to tin better than when a shorter time is allowed them.

From this pot they are removed, with the grease still adhering to them, into the pot just before spoken of, which contains the body of melted tin; and in this they are placed in a vertical position. Three hundred and thirty-eight or three hundred and forty plates are usually put into this pot at once¹; and for the sake of their being thoroughly tinned, they usually remain in it one hour and a half; but occasionally more time is required to complete this operation.

When the plates have lain a sufficient time immersed in the melted tin, they are taken out and placed upon an iron grating, that the superfluous metal may drain from them; but, notwithstanding this precaution, when they become cold there is always more metal found adhering to them than is necessary; and this is taken off by a subsequent process called *washing*. As this process is rather complicated, it will be necessary to describe it with some minuteness.

In the first place, the wash-man prepares an iron pot which he nearly fills with the best grain-tin in a melted state—another pot of clean melted tallow, or lard free from salt—a third pot with nothing within it but a grating to receive the plates—and a fourth, called the *listing-pot*, with a little melted tin in it, about enough to cover the bottom to the depth of a quarter of an inch. The whole will however be better understood by referring to the following drawing, which exhibits the several vessels in the order in which they stand in the manufactory, all supported by substantial brick-work.

¹ It is immaterial how many plates are put into the tin-pot at once—but this number is usually fixed upon, because it amounts to about one box and a half of plates: though, as they are put in edgewise, it is necessary the pot should be nearly filled, to prevent their falling down—in which case they could not be got out, through so heavy a body of metal, without much difficulty.



The building in which the pots are fixed is called the *Stow*. The plates are worked from the right to the left of the stow, as will be evident by attending to the uses of the separate pots.

No. 1. represents the tin-pot.

2. The wash-pot with the parting within it.

3. The grease-pot.

4. The pan, containing a grating at the bottom, for the reception of the plates as the boy takes them out of the grease-pot. It has no fire underneath it.

5. The list-pot.

The drawing represents the *surface* of the pots. The asterisks show the places where the workmen stand, and also mark those pots which have heated flues under them. No. 4 has no fire under it.

The parting in the wash-pot No. 2 is a late improvement. The design of it is to keep the dross of the tin from lodging in that part of the vessel where the last dip is given to the plates. By using the *common* tin in the first process of tinning, much oxide, or dross, adheres to the surface of the plates, and this runs off in the wash-pot, and comes to the face of the new metal; but this parting enables the operator to prevent it from spreading over the whole surface of the pot. Were it not for this parting, the wash-man must skim the oxide off the fluid metal every time he puts plates into it.

The pots of which I have given a sketch being all in a state of fitness, the wash-man commences his part of what remains of the business, by putting the plates which have undergone the various operations hitherto described into the vessel of grain-tin, called the wash-pot². The heat of this large body of melted metal soon

² None but *grain-tin* is ever put into this vessel; for the whole of the common tin which is consumed in such manufactories, is used in the *first* process, viz. that which is called *tinning*.

melts all the loose tin on the surface of these plates, and so deteriorates the quality of the whole mass, that it is usual, when sixty or seventy boxes have been washed in the grain-tin, to take out the quantity of a block, say three hundred weight, and replenish the wash-pot with a fresh block of pure *grain-tin*. These vessels generally hold three blocks each or about half a ton weight of metal. That which is taken out of the wash-pot when it is replenished with pure metal, is given to the tin-man to put into his pot.

When the plates are taken out of the wash-pot, they are carefully brushed on each side with a brush of hemp of a peculiar kind, and made expressly for the purpose. As this part of the business requires considerable adroitness and expedition, it may be worth while to explain it a little more in detail.

The wash-man first takes a few plates out of the wash-pot, and lays them together before him on the stow; he then takes one plate up with a pair of tongs, which he holds in his left hand, and with a brush held in his right hand brushes one side of the plate; he then turns it, and brushes the other side, and immediately dips it once more into the hot fluid metal in the wash-pot, and without letting it out of the tongs instantly withdraws it again, and plunges it into the grease-pot (marked No. 3) adjoining to the wash-pot from whence he had just taken it.

A person who has not seen the operation, can form but a very inadequate idea of the adroitness with which this is performed: practice, however, gives the workman so much expedition, that he is enabled to make good wages, although he obtains only three-pence for the brushing and metallic-washing of 225 plates. I am informed that an expert wash-man, if he makes the best of his time, will wash 25 boxes, consisting of 5625 plates, in twelve hours; notwithstanding every plate must be brushed on both sides, and dipped twice into the pot of melted tin.

Why the plates should be dipped *twice* during this part of their manufacture, may perhaps require some explanation. It must be recollected that they are brushed quite hot, and before the tin is set; therefore, if they had not the last dip, the marks of the brush would be visible. Moreover, the brush takes the greatest part of the tin off them, so that if they were removed to the grease-pot without being re-dipped, the hot grease would take off what remained.

The only use of the grease-pot is to take off any superfluous metal that may be upon the plates: but this is an operation that requires great attention, because, as the plate is immersed in the grease while the tin is in a melting, or at least in a soft, state upon it, a part *must run off*, and the remainder become less and less while the plate continues in it; therefore, if these plates

should ever be left in the melted tallow longer than is absolutely necessary, they will doubtless require to be dipped a third time in the tin. On the other hand, if the plates were to be finished without passing through the grease, they would retain too much of the tin, which would be a loss to the manufacturer; and besides, the whole of the tin would appear to be *in waves* upon the iron.

It is also equally necessary to attend to the temperature of the melted tallow, which must be colder or hotter in proportion as the plates are thicker or thinner; for if, when the tallow is of a proper temperature for a thin plate, a thick one was to be put into it, it would come out, not of the colour of tin as it ought to be, but as yellow as gold. The reason of this is evident. The thick plate contains more heat than a thin one, and consequently requires the tallow to be at a lower temperature. On the contrary, if a parcel of *thin* plates were to be worked in a pot of tallow which had been prepared for *thick* plates, such a pot would not be hot enough to effect the intended purpose.

It is a common observation that in most of our manufactures, and in all chemical speculations, theory and practice are generally at variance: but there are few manufactures, perhaps, where there are so many minutiae which would escape the notice of a casual observer, and yet that require to be carefully attended to, in order to produce a good result, as in that which we have now been describing; and should the perusal of this paper occasion but one individual to pause, who was about to enter into a new concern with which he was only partially acquainted, I shall have written to a good purpose.

But to return to the process. When the plates are sufficiently brushed, they are again immersed one by one in the pot of melted tin, as has already been remarked, and immediately from this they are put into the pot of tallow above mentioned. This pot has pins fixed within it, in such a manner as to prevent the plates from touching each other; and this part of the process is conducted in the following manner:

When the wash-man has passed *five* of the plates through the melted tin, and from thence into the pot of tallow above mentioned, a boy takes out one of them and puts it into the empty pot to cool, and the wash-man puts in the *sixth* plate. The boy then takes out a *second* plate, and lays it to cool likewise; when the man puts in his *seventh*, and so they go on, in this regular manner, until the whole of the parcel is finished.

In consequence of the plates being immersed in the melted tin in a vertical position, there is always, when they have become cold, a wire of tin on the lower edge of every plate which is necessary to be removed, and this is done by a boy, called the list-boy, who takes the plates when they are cool enough to handle, and puts the

lower edge of each, one by one, into the list-pot, which is the vessel that was before described, as containing a very small quantity of melted tin, and the same as that which I have marked No. 5. When the wire of tin is melted by this last immersion, the boy takes out the plate, and gives it a smart blow with a thin stick, which disengages the wire of superfluous metal, and this falling off, leaves only a faint stripe in the place where it was attached. This mark may be discovered on every tin-plate which is exposed for sale; the workmen, in the manufacture of them, call it the *list*.

Nothing now remains but to cleanse the plates from the tallow. This is done by means of bran, and as they are cleansed they are put into strong wooden boxes, or boxes of *sheet-iron*, made exactly to fit them; and this completes the whole business. Each box contains a determinate number of plates; and the following table will show the different sizes of tin plate which are made in Great Britain, the marks by which each kind is known in commerce, and the current wholesale prices of each size.

Names.	Sizes.	No. in a Box	Weight of each Box.			Marks put on the Boxes	Prices per Box in Sept. 1817.	Prices per Box in 1830.
							s.	s.
Common . . . No. 1.	13 $\frac{3}{4}$ by 10	225	1	0	0	CI	41	40
Do. 2.	13 $\frac{1}{4}$ by 9 $\frac{3}{4}$		3	21		CH	39	38
Do. 3.	12 $\frac{3}{4}$ by 9 $\frac{1}{4}$		3	16		CHI	37	36
Cross No. 1.	13 $\frac{3}{4}$ by 10		1	1	0	XI	49	46
Two Cross 1.			1	1	21	XXI	55	52
Three Cross 1.			1	2	14	XXXI	61	56
Four Cross 1.			1	3	7	XXXXI	67	64
Common Doubles . . .	16 $\frac{3}{4}$ by 12 $\frac{1}{4}$	100		3	21	CD	37	36
Cross Doubles			1	0	14	XD	45	42
Two Cross do.			1	1	7	XXD	51	48
Three Cross do. . . .			1	2	0	XXXD	57	54
Four Cross do.			1	2	21	XXXXD	63	60
Com. small Doubles . .	15 by 11	200	1	2	0	CSD	63	62
Cross do. . . do. . . .			1	2	21	XSD	69	68
Two Cross . . do. . . .			1	3	14	XXSD	75	74
Three do. . . do. . . .			2	0	7	XXXSD	81	80
Four do. . . do. . . .			2	1	0	XXXXSD	87	86
Wasters Com. . . No. 1.	13 $\frac{3}{4}$ by 10	225	1	0	0	WCI	35	34
Do. Cross . . . 1.	13 $\frac{3}{4}$ by 10		1	1	0	WXI	43	40

Having given so detailed an account of the manufacture of tin-plate, it may be expected that I should say a few words on the *origin* of the art.

Formerly none of the English workers in iron or tin had any knowledge whatever of the methods by which this useful article could be produced; our ancestors, from time immemorial, hav-

ing supplied themselves with it from Bohemia and Saxony. The establishment of this manufacture in those districts, was doubtless owing to their vicinity to the tin mines in the circle of Ersgebirg, which, next to those of Cornwall, are the largest in Europe. The ore which is found there is not the *tin-pyrites*, but the mineral called *tin-stone*; and it is curious that it should occur in abundance, both on the Bohemian and Saxon sides of the mountain group: accordingly, manufactories of tinned iron have been established in both those kingdoms. Alluvial deposits of grain-tin are also found in the same vicinity.

From the time of the invention of tin-plate to the end of the seventeenth century, not only England but also the whole of Europe depended upon the manufactures of Bohemia and Saxony for their supply. However, about the year 1665 Mr. Andrew Yarranton, encouraged by some persons of property, undertook to go over to Saxony to acquire a knowledge of the art; and on his return, several parcels of tin-plate were made of a superior quality to those which we had been accustomed to import from Saxony; but owing to some unfortunate and unforeseen circumstances, which are all detailed by Mr. Yarranton in his very valuable publication¹, the manufactory was not at that time established in any part of Great Britain.

As it is now difficult to procure a copy of the work from which I have obtained a knowledge of the manner in which this manufactory was brought into England, an abridgement of the author's own account of the transaction will probably be interesting to the public.

“Knowing,” says Mr. Yarranton, “the usefulness of tin-plates, and the goodness of our metals for that purpose, I did (about sixteen years since²) endeavour to find out the way for making thereof; whereupon, I acquainted a person of much riches, and one that was very understanding in the iron manufacture; who was pleased to say, that he had often designed to get the trade into England, but never could find out the way. Upon which it was agreed, that a sum of monies should be advanced, by several persons, for the defraying my charge of travelling to the place where these plates were made; and from thence to bring away the art of making them. Upon which, an able fire-man, that well understood the whole nature of iron, was made choice of to accompany me; and being fitted with an ingenious inter-

¹ *England's Improvement by Sea and Land*, with many plates of Plans, Charts, &c. in two parts, by Andrew Yarranton, Gent. Part I. Quarto. London, 1677. Part II. London, 1681.

² This account is dated February 2nd, 1681; I therefore conclude that Mr. Yarranton's journey to Saxony must have been about the year 1665.

preter, that well understood the language, and that had dealt much in that commodity, we marched first for Hamburg, then to *Lips-wick*; and from thence to *Draidsen*, the duke of *Saxonies* Court, where we had notice of the place where the plates were made; which was in a large tract of mountainous land, running from a place called *Segèr-Hutton*, unto a town called *Awe*, being in length about twenty miles; the tin-works being there fixed upon a great river running clear along the valley, and also upon some little rivulets that run out of the mountains of Bohemia and Saxony; and coming to the works, we were very civilly treated, and, contrary to our expectation, we had much liberty to view, and see the works go—with the way and manner of their working and extending the plates, as also the perfect view of such materials as they used in clearing the plates, to make them fit to take tin, with the way they use in tinning them over, when cleared from their rust and blackness. And having (as we judged) sufficiently obtained the whole art of making and tinning the plates, we then came for England, where the several persons concerned in the affair thought fit to make some trial in making some small quantities of plates and tinning them, which was done; and all workmen that wrought upon them agreeing that the plates were much better than those which were made in Germany; upon which, preparation was making to set this beneficial thing at work;—but, it being understood at London, A PATENT was trumped up, and the patentee was countenanced by some persons of quality—and what with the patent being in our way, and the richest of our partners being afraid to offend great men in power, who had their eye upon us, it caused the thing to cool, and the making thereof was neither proceeded in by us, nor possibly could be by him that had the patent; because neither he that hath the patent, nor those that have countenanced him, can make one plate fit for use¹.”

This enterprising individual, who spent the greater part of his life in promoting schemes for the good of his country, and who, in the opinion of Bishop Watson, ought to have had a statue erected to his memory, proceeds to inform us, that before they were stopped by the patent they had made “many thousand plates from iron raised in the forest of Dean, and tinned them over with Cornish tin, and the plates proved far better than the German plates, by reason of the toughness and flexibleness of our forest iron. One Mr. *Dison*,” says he, “a tinman in Worcester, one Mr. *Lydiate* near Fleet-bridge, and one Mr. *Harrison* near the Kings-bench, have wrought many, and they know their goodness².”

In another place this interesting writer informs us, that “when he was in Saxony the different establishments for making tin-plates

¹ *England's Improvement*, &c. p. 149—152, Part II.

² Page 173.

were very numerous, and that most of them belonged to the duke³." "The trade," says he, "is so great, that by computation, no less than 80,000 men depend upon it; and when the plates are finished, they are sent by land to *Lipsick*, from thence to the *Elbe* river, and so down to *Hamburg*, and from thence sent by sea as far as trade is known⁴." "There was," says he, "no tin any where in Europe, except in Cornwall, until a Cornish man found tin in the mountains of Saxony, near a town called *Awe*, where *his statue is yet to be seen*. The tin works are fixed upon a great river running down the valley; and the tin, iron and woods, grow in and upon the mountains adjoining to both sides the river; and those tin-works have proved so beneficial to the place, that there are several fine cities raised by the riches proceeding therefrom⁵." He adds, "The trade of making tin-plates was about sixty years since fixt in Bohemia, and had there long continued; but the woods decaying, and there being at that time a wise duke of Saxony, willing and ready to improve his own revenue, and his subjects, did accept of directions how this trade might be brought away and fixt in the duke of Saxony's territories⁶.—A Romish priest, converted to be a Lutheran, was the chief instrument in the whole affair, until it was perfected—and a Cornish miner, a Protestant who had been banished out of England for his religion, found out the tin in Saxony—both which persons proved instruments of great wealth to that duke and country⁷."

The following particulars which I have collected respecting Mr. Yarranton, will justify Bishop Watson in the opinion he has given of him.

He was bound as an apprentice, early in life, to a linen draper, but after some years he left that situation in disgust. In the year 1652 he took some iron works, which he carried on for several years; and during this period he made regular surveys of the three great rivers in England, and by means of associations which were formed by himself, he rendered three other rivers navigable: he studied agriculture with such effect, that many of the arable estates in the midland counties were rendered doubly productive by the new methods of husbandry which he either brought from abroad, or discovered;—he laid a plan for the junction of the Thames and Severn *at that spot* where of late years this very scheme has been effected;—he proposed the cutting of several navigable canals, half a century before any such project had been executed in this country. He made the necessary sur-

³ *Ibid.* 155. ⁴ Page 172. ⁵ Yarranton, part II. p. 176. ⁶ *Ibid.* p. 178.

⁷ Saxony is separated from Bohemia by a chain of mountains called the *Erzegebürg*; which in German signifies, hills that contain mines.

veys and planned docks for the cities of London and Dublin:—besides his journey to Saxony already mentioned, he went to Holland, under the patronage of the ancestors of some of our present nobility, to examine the inland navigations of the Dutch, and to investigate the nature of their linen manufactures;—and on his return promulgated the plan for a new manufacture of linens, which he calculated would employ all the poor of England. He published schemes for the improvement of our national fisheries; he made several tours through Ireland, for the express purpose of planting new manufactures and devising the increase of the staple trades of that country: he made a regular survey and estimate of the expense of rendering the river *Slade* in Ireland navigable for the purpose of bringing timber down to the coast for His Majesty's navy; and rendered many other signal services to his country.

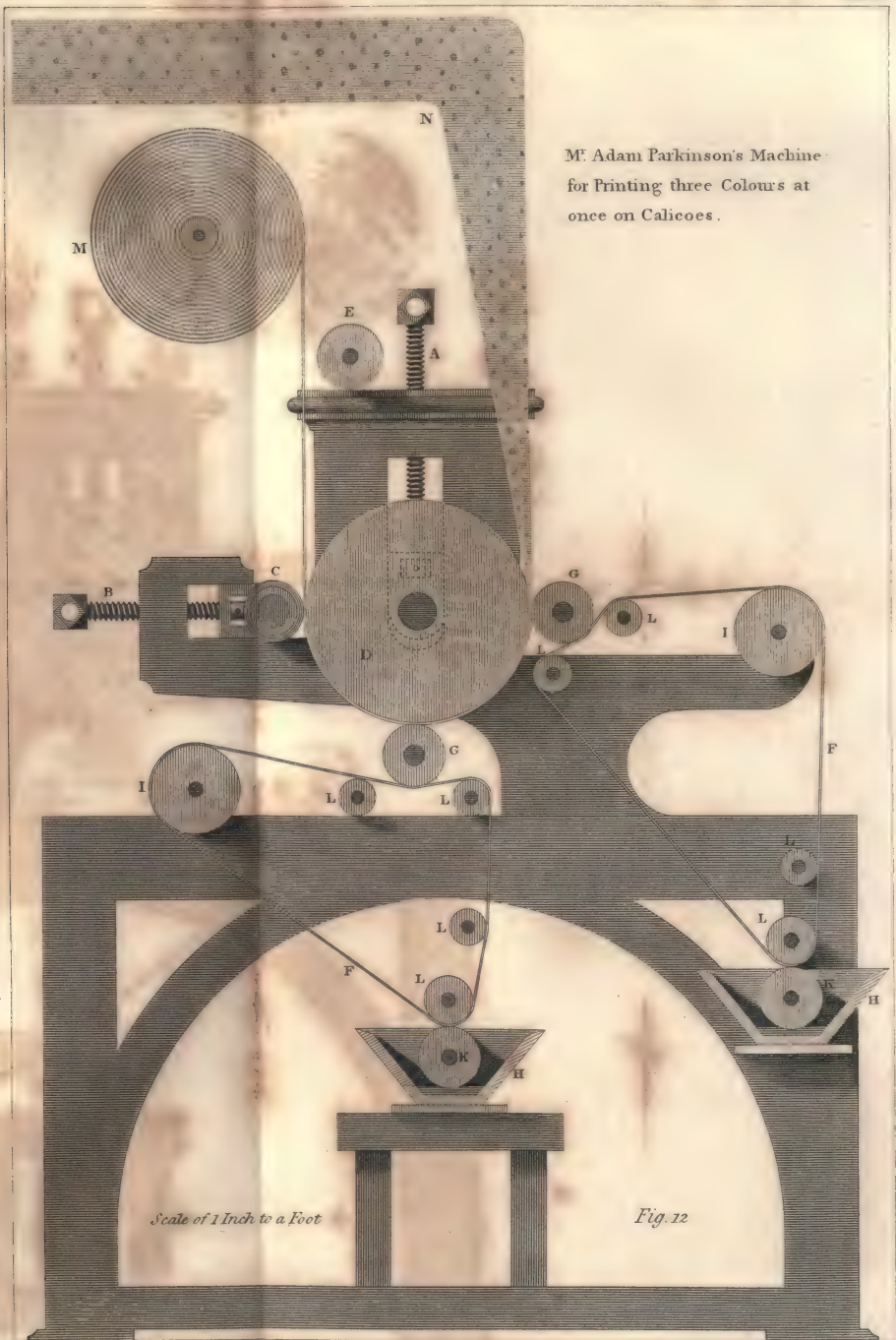
Notwithstanding Mr. Yarranton had so completely introduced the knowledge of making tin-plate into this country, I do not find that any manufacture of that article was established in these kingdoms until some time between the years 1720 and 1730, which must have been long after Mr. Yarranton's death. The first establishment of this kind, was fixed at the town of Pontypool, in Monmouthshire, where it continued to flourish many years; and it is remarkable, that after the lapse of nearly a century, the manufacture has recently been re-established at the same town on a very extensive scale.

About the time that this manufactory was established, the amiable and intelligent M. Reaumur, to whom the French are indebted for a new mode of graduating the thermometer, for introducing the methods of making porcelain into France, and for many discoveries and improvements in the arts,—undertook to discover the method of making tin-plates for the French people. This eminent man, whose mind was cast in a mould very similar to that of Mr. Yarranton, but who possessed more science, never relinquished any thing which he undertook; and accordingly, notwithstanding the innumerable difficulties which he had to encounter, at length succeeded in acquiring such a knowledge of the principles of the manufacture, as enabled him to instruct several people in the vicinity of Paris, in an art which, until then, had never been practised in that country.

Soon after the time of which I am speaking, several similar manufactories were erected in Great Britain; and now the establishments of this nature are so numerous and extensive in many parts of these kingdoms, that the manufacture of tin-plate is become of great national importance, and more than one hundred thousand boxes of these plates are annually exported.



M^r Adam Parkinson's Machine
for Printing three Colours at
once on Calicoes.



Scale of 1 Inch to a Foot

Fig. 12

ESSAY XVII.

ON CALICO-PRINTING.

CALICO-PRINTING is an art of very considerable importance to this country; it has proved the source of immense wealth to many individuals, and for several years past has brought a great revenue to the state. Notwithstanding its value and national consequence, the majority even of well-informed people know little or nothing of the processes by which this peculiar manufacture is conducted.

This ignorance will appear the more remarkable, when it is considered that linens were fabricated, and the arts of dyeing and staining garments, something like the present calico-printing, were known and practised in the earliest ages of which history gives us any detail.

Hence it may very fairly be presumed that a faithful account of the nature of this business would be very acceptable to the public, and that, in the course of the narration, if any improvements on the present practice should be suggested, it is possible that such an account may not, even to the calico-printer himself, be totally uninteresting and useless.—We shall begin with an attempt to trace the history of the art, and of its progress towards that perfection to which it has now attained.

In the time of Moses the land was employed for the growth of flax as well as of corn; and that this flax was used for the fabrication of cloth, may be collected from a variety of circumstances, especially from an examination of some Egyptian mummies, the most ancient of which (at least such as have been brought to Europe) are bound round with folds of linen similar to the flaxen cloth of the present day.

There is a paper of Dr. Hadley, in the fifty-fourth volume of the Philosophical Transactions, giving an account of the examination of an Egyptian mummy, in the presence of several of the Fellows of the Royal Society. After describing its general appearance, he says, "The outward painted covering being removed, nothing but linen fillets were to be seen, which inclosed the whole mummy. The uppermost fillets were of a degree of fineness nearly equal to what is now sold in the shops under the name of long lawn, and were woven something after the manner of Russian sheeting." This mummy was taken from a catacomb

near Cairo; and when the age of these catacombs is considered, it gives great antiquity to the art of weaving fine linen.

We have evidence, however, that the invention of weaving is still more ancient than even the times when the embalming of the Egyptian mummies was in vogue. This is evident from the answer which Abram gave to the King of Sodom:—"I will not," said he, "take from a thread of the woof, even to a shoe-latchet, lest thou shouldest say, I have made Abram rich." *Genesis* xiv. 23.

Moses informs us that Abimelech made a present of a veil to Sarah. He observes also, that Rebecca covered herself with a veil, when she perceived Isaac; and that Pharaoh arrayed Joseph in a vesture of fine linen or cotton, when he made him viceroy of Egypt. A weaver's shuttle is also mentioned in the Book of Job, chap. vii. 6. These facts incontrovertibly prove the great antiquity of the art of weaving with warp and woof.

In these very ancient times this work was performed in a standing posture¹, which was owing to the construction of their looms, in which the warp was extended perpendicularly from top to bottom, and kept firm by means of a piece of wood, to which they hung very heavy weights².

"Inventress of the woof, fair Lina flings
The flying shuttle through the dancing strings,
Inlays the broider'd weft with flowery dyes,
Quick beat the reeds, the pedals fall and rise;
Slow from the beam the lengths of warp unwind,
And dance and nod the massy weights behind."

Five hundred years after the death of Moses, and nearly a thousand years before Christ, it is related that Solomon imported linen yarn from Egypt: and after this period the city of Tyre is represented as abounding in fine linen; for, when Ezekiel is describing the grandeur of that city, and the opulence of her merchants, he says: "They have made all thy ship-boards of fir trees of Senir; they have taken cedars from Lebanon to make masts for thee; FINE LINEN with broidered work from Egypt, was that which thou spreadest forth to be thy sail."—*Ezekiel* xxvii. 7.

From the manner in which this is introduced, it is evident that the writer considered fine linen to be an article of great rarity. In his days *matting* was commonly used for sails; hence sails of *linen* must have been thought extremely magnificent. "The sails of the ancient Phœnicians were made of different substances,

¹ Junius *de Pictura Veter.* lib. i. cap. 4. p. 26.

² Goguet's *Origin of Laws, &c.* vol. i. p. 126.

such as hemp, rushes, long-leaved plants, mats, and skins.—Yet those of the Greeks at the same period were most commonly of cloth³.” Sails of matting are still used on the vessels navigated by the Arabs on the Red Sea. We are entitled however, from this body of concurrent testimony, to conclude, that linen cloth has been in use, though perhaps not very commonly, from the time of Moses to the present day.

On the other hand we have the positive evidence of Pliny, that in his time there were many ancient families at Rome, who boasted of never having admitted linen cloth into their houses, considering the use of it as a mark of great and criminal effeminacy⁴.

Pliny says also, that “Lentulus Spinter was the first man who in the games drew fine curtains over the great amphitheatre of Rome; and that not long after this, Cæsar Dictator caused the high fair street called *Sacra* to be hung on both sides, from his own dwelling-house to the very Capitol; which magnificent and sumptuous sight was much wondered at, and seen with great admiration.” He adds, that “Alexander the Great was the first person who had sails or linen flags that were dyed with colours, that he borrowed it from the Indians, and that afterwards a red purple banner erected on the top of the mast was the badge of the royal admiral’s ship.”—Holland’s Pliny, vol. ii. p. 5.

Equally decisive is the testimony of history respecting the antiquity of coloured linens, which appear to have been known almost in the very earliest ages.

More than three thousand years ago, a shrewd matron tied a scarlet thread round the hand of one of Tamar’s children⁵; and Homer, who flourished nine hundred years before Christ, speaks of the variegated cloths of Sidon as very magnificent productions⁶.

The books of the Pentateuch frequently mention the ornaments for the Tabernacle, as composed of blue and purple and scarlet and fine linen; and it has been remarked by Mr. Delaval, that in those ancient writings these colours are constantly arranged exactly in the same order⁷, and that this order is the true prismatic series of those colours.

This is certainly a very striking fact; and it is also not a little curious, that after a lapse of several centuries which intervened between the period described in Exodus and the time of Solomon,

³ Goguet’s *Origin of Laws*, &c. vol. ii. p. 326.

⁴ Plin. *Hist. Nat.* lib. ix. c. 1.

⁵ *Genesis* xxxviii. 27. ⁶ *Iliad*. lib. vi. line 289.

⁷ See *Exodus* xxv. 4. xxvi. 1. 31. 36. xxvii. 16. xxviii. 6. 8. 15. xxxv. 6. 23. 25. 35. xxxvi. 8. 35. 37. xxxviii. 23. xxxix. 1—29, and several other places.

the colours employed in the Temple ornaments should be still mentioned in the same order as those of the Tabernacle had been formerly noticed ; which is exactly the case, excepting in one single instance, where the red is called *crimson* instead of scarlet¹.

May not this very interesting fact be considered as an internal proof of the antiquity of the sacred writings? We know how much mankind have at all times been addicted to the practice of imitating Nature ; and next to the great luminary of our system, the rainbow was surely the grandest object which the writers of these early books had ever beheld.

I must not, however, forget that I shall be expected to give some account of the progress of the art of staining, painting, or printing linen and calico.

Herodotus, who wrote more than four hundred years before the commencement of the Christian æra, when describing the nations which inhabited Caucasus, a mountain extending throughout the region of Georgia and Armenia, affirms that by means of vegetables ground and diluted with water, these people adorned their cloth with the figures of various animals, and that the dyes were permanent which were thus obtained.

Valerius Flaccus, an historian who wrote in the age immediately succeeding that of Christ, distinguishes a warrior slain at Colchis, during the Argonautic expedition, by a *painted* garment, and at the same time specifies that his dress was of fine white linen.—Lib. vi. 221 et seq.

That dyeing materials were, in ancient times, plentifully produced at Colchis and Tournefort, is well known ; and according to Mr. Delaval, great quantities of these materials are still used in the very same species of dyeing. Besides, more than two thousand camel loads of madder are annually sent from Georgia to Diurbeck and India, where the finest calicoes are still printed or painted with it².

Strabo, the Greek philosopher, who was contemporary with our Saviour, relates that the Indians wore flowered linens³, and that India abounded with drugs, roots, and colouring substances, from which some very beautiful dyes were produced⁴; and we know that the inhabitants of India used a purple and scarlet dye resembling cochineal in colour and in the manner of its production.

Moreover, the statues of Isis, which formerly were so abundant in Egypt, were generally adorned with *parti-coloured* cloths, which, as has been remarked, must have been of linen, or of cotton⁵, because woollen was so much abhorred by the Egypt-

¹ 2 *Chronicles* iii. 14.

² Delaval, p. 21.

³ Strabo, lib. xv. p. 709.

⁴ Strabo, lib. xv. p. 694—699, *de India*.

⁵ Delaval, p. 34.

tians that the lowest of the people would neither use it ⁶ nor allow it to be employed even in their interments. Such indeed was their aversion, that it extended to the flocks, and to the very shepherds themselves who attended them. "Every shepherd," says the writer of the Pentateuch, "is an abomination unto the Egyptians".—*Genesis* xlv. 34.

The methods which the Egyptians adopted to produce these parti-coloured linens is very particularly described by the Elder Pliny, who perished by an eruption of Vesuvius in the year 79 of the Christian æra. "The Egyptians," says he, "began by painting, or drawing, on white cloths with certain drugs, which in themselves possessed no colour, but had the property of attracting or absorbing colouring matters. After which, these cloths were immersed in a heated dyeing liquor; and though they were colourless before, and though this dyeing liquor was of one equable and uniform colour, yet when taken out of it soon afterwards they were found to be wonderfully tinged of different colours, according to the peculiar natures of the several drugs which had been applied to their respective parts; and that these colours could not be afterwards discharged by washing.—*Plin. lib. xxxv. cap. 11. § 42.*

The agreement which there is between this account of the management of the ancients and the present practice, cannot fail to strike any one who is at all conversant with the processes now in use. And from this relation, and other testimony still on record, there can be no doubt but that these people employed both iron and alum as mordants, though these mordants might not be prepared exactly in the same way, or in so effective a manner, as they are by the moderns.

Native soda, which abounded in Egypt, was also known to the ancients; and we have the direct assurance of Pliny that the dyers of antiquity were in the habit of using it in their processes.—*Lib. xxxi. cap. 10.*

But amongst the countries of the East which practised dyeing, the Phœnicians were the most celebrated, and particularly for their purple colour. So great was the demand for this article, that the city of Tyre grew to a vast extent, from the number of workmen employed in its manufacture; and it was from a sense of the great national utility of their purple dye, that the Phœnicians attributed its invention, which was the principal foundation of their trade and wealth, to the gods.—*Strabo, lib. xvi. 757.*

Besides the purple which was thus prepared at Tyre and other

⁶ "And it shall come to pass, that when they enter in at the gates of the inner court, they shall be clothed with linen garments, and no wool shall come upon them."—*Ezekiel* xlv. 17.

parts of Syria, the ancient inhabitants of India were also in the habit of using a purple and scarlet dye, which they procured from the cochineal insect, or from some other insect resembling it. For Ctesias, who flourished about four hundred years before Christ, and was a great favourite at the court of Persia, and Ælian the philosopher, who taught rhetoric at Rome in the reign of Alexander Severus, both give an account of the insects which yielded it, and of the plants on which they fed. We also learn that so large a quantity of this colouring matter was produced in India, as to become an article of export in those early times. It is probable, therefore, that it was by means of this insect, whatever it might be, that these Asiatics were supplied with that abundance of purple, which enabled even the lowest ranks among them to wear clothes of that colour¹.

There can indeed be little doubt but that the true cochineal, was known in Persia very early. The king of Persia, we are told, sent to the emperor Aurelian, among other things of value, some woollen cloth which was of a much brighter purple than any that had ever been seen in the Roman empire, and in comparison of which all the other purple cloth worn by the emperor and the ladies of the court appeared dull and faded².

From various accounts it appears, that formerly, in India, the cotton cloths, when brought from the weavers, partly bleached, were worn next to the skin, by the dyer and by all his family, during the space of eight or ten days. These cottons could not however have been of a length equal to the pieces of the present day; they were probably nothing but the mere shawls, which have been common in India from time immemorial. Among the magnificent dresses of the present Asiatics, there is nothing more esteemed than shawls of various colours, and these are frequently given to the great by way of presents.

When the cloth had been thus worn until it was thoroughly soiled, the several pieces underwent repeated macerations in water, with goats' dung, and were afterwards submitted to frequent washings and to as frequent dryings in the rays of an intense sunshine. Afterwards, they were soaked for some time in the mixture of the astringent fruit of the yellow *myrobalans*, and of curdled buffalo's milk. When thoroughly impregnated therewith, they were squeezed, dried by exposure to the sun, and then, by pressure and friction, they were made smooth enough for being drawn upon by the pencil, with the different mordants.

The first of these mordants was an iron liquor, made by dissolving iron in a mixture of sour palm wine and rice-water, or

¹ See Delaval's preface, p. 24.

² Beckman, from Vopiscus in *Vita Aureliani*, cap. 29.

water in which rice had been boiled for a considerable time. This liquor was applied to the figures or spots intended to become black, and afterwards the aluminous mordant was applied, commonly by children, with the pencil, to the parts intended to be made red. The pieces were then exposed to the hottest sunshine, that the parts to which the mordants had been applied might be dried as much as possible; and then they were thoroughly soaked in pits of water, to cleanse them from the superfluous mordants, as well as from the buffalo's milk, &c.; and lastly, they were dyed in water, with certain roots answering nearly in their effects to those of madder.

It was in this way the manufacture of printed cottons was conducted by the Indians, in *former* times. The following is an account of the *modern* practice, in one particular branch of their manufacture, which I procured from a gentleman who has spent some time in India, and which I now subjoin, rather for the amusement than the instruction of the British calico-printer.

The finest cotton chintz counterpanes, says he, which the natives call pallampoor, are manufactured at Madras. These are woven in one piece from two to four yards square, and are printed, or rather painted, with various designs, and in various colours. Their method is to draw the pattern first on sheets of paper sewn together, of the size of the intended pallampoor; and then to prick out the same in the paper with a sharp instrument. When this is done, the paper pattern is smoothly fixed upon the cloth, which is previously dampened, and then a small muslin bag containing some kind of black powder is rubbed over the whole, in order to pass a part of the powder through the pin-holes, and completely mark out the pattern.

The pattern being thus sketched upon the cloth, the paper is removed; and when the outline of the various figures is drawn with a pencil, the piece is considered to be ready for receiving the colours.

One colour is then laid on with a brush made with a tough root of a particular kind of tree, or with the husk of the cocoa nut; and when this is dry, the piece of cotton is given to a woman to wear, or to use in the family, till it be very much dirtied; in order that it might necessarily undergo a thorough washing, which is thought requisite to prove the goodness and permanency of the colour. Another colour is then laid on in the same manner, and the piece is again submitted to the same trial of wearing and washing. The Asiatics may not be aware of it; but doubtless the long exposure to the air in these cases, is the important point, as it is well known that the atmosphere is a prime agent in rendering many colours permanent, which under a different treat-

ment would be heavy and fugitive. This management is repeated for every colour that is employed;—and when any one of these colours is found to be deteriorated by this treatment, it is printed afresh; and so are all the rest, till the workman is satisfied that all the colours are actually permanent.

This tedious process is adopted, however, only when the manufacturer means to warrant the article; but in all cases, even in those pieces which will not bear washing, the colours are laid on by a brush, as before mentioned.

Whether they are all substantive colours which are thus applied, or whether they use any species of mordant in their fast work, I am unacquainted, as my friend had no information on this subject.

Such are the facts which I have been able to collect respecting the progress of calico-printing from the earliest ages; and also of the present state of the art among the Asiatics. The more difficult part now remains, viz. to give a brief detail of the most important processes of our own artists. This, however, I shall endeavour to do with the utmost plainness, and shall not fail to suggest any improvement that may have occurred to me during my inquiries respecting this very interesting and varied branch of manufacture.

I have not yet been able to ascertain when calico-printing was introduced into this country, though there are various reasons for believing that it is an art, among us at least, but of modern date.

As the whole of this ingenious business, as it is now conducted, depends upon the proper application of a few compounds called mordants, it will be necessary, in the first place, to explain their nature and uses. In doing this, one or two preliminary remarks will assist us.

The colouring substances chiefly employed in this art, are divided into two classes, viz. *substantive* and *adjective*. A *SUBSTANTIVE* colour is one which is capable of itself of producing a permanent dye; such is the juice of the buccinum, used by the ancients for producing the imperial purple; such are also the woad and indigo employed by the moderns for producing a permanent blue; and we may add the metallic solutions, particularly those of iron, cobalt, gold, platinum, and silver, which give various colours, according to the processes by which they are prepared.

By *ADJECTIVE* colours are meant all those which are incapable of giving permanent dyes without the aid of certain intermedia, which form as it were a bond of union between them and the substances intended to be dyed.

These intermedia are what are known by the term MORDANTS, and they are used for this purpose in very considerable quantities by the calico-printer of the present day.

Several expedients were employed by the ancients to produce fast, or, more properly, permanent colours, by means of mordants, as appears from the testimony of Aristotle and Pliny. The chief articles in use at present in Great Britain, are the acetate of iron, the acetate of alumina, and the various solutions of tin, all of which should be very carefully and correctly prepared.

When piece-goods are designed to be dyed of one uniform adjective colour, they are first immersed in a solution of one of these mordants, and are then hung up to dry and to absorb the oxygen of the atmosphere. When sufficiently exposed to the air, they are washed or dunded¹, to remove the superfluous mordant; that is to say, that part of it which is not chemically combined with the cloth; and the pieces are then submitted to a bath of that particular kind of colouring matter which is to be imparted to them.

Whenever it is meant that a colour should be partially inserted, the mordant is applied to those particular parts only; so that, when the piece is immersed in the colouring bath, no other place will receive the permanent stain. For though the whole surface of the cloth will be coloured, yet having in itself no affinity with the vegetable with which the decoction is impregnated, the whole of the colouring matter will be easily removed by exposure to the air, and the ground of the piece restored to its original whiteness; while those parts to which the mordant was applied, will retain and fix the colours in a way which will be more fully explained hereafter.

In my opinion every printer should bleach his own goods, for it is impossible always to rely with confidence on the care of those who bleach for hire; and good bleaching is absolutely a necessary preliminary in the production of good printing.

No people have taken more pains to excell in bleaching than the Irish, and their credit is established accordingly. The German linen is, I believe, generally better than theirs; but the Irish has always the preference in foreign markets, owing to the superiority of the Irish in bleaching and finishing. Chloride of lime is the agent generally employed in bleaching, a minute de-

¹ The dung of the cow is used in such large quantities by the calico-printer, that it has become an article of great expense. The proportion that is employed is usually about one bushel to one hundred gallons of water, though frequently a larger proportion would be more effectual. The brightness of the colours, and the purity of the whites, are always dependent upon the quantity of the dung employed.

scription of which process will be found detailed in the Essay on Bleaching.

By whatever means the bleaching is performed, the printer commences his part of the business in the following manner.

The goods are first DRESSED by singeing off the whole of the nap which is attached to them. This is effected by the following contrivance: Ten pieces are generally wired together, and wound upon a roller, from whence they are passed over a hot iron, nearly in the form of half a cylinder, and received upon another roller; from thence they are returned to the iron, which is still kept red or nearly at a white heat¹. The use of repeating this process is to remove the nap more effectually than it would be done by passing it only once over².

The next operation is that of STEEPING, which consists merely in soaking the pieces for 24 hours in a vessel of weak alkaline lye, at a temperature of about 100°. These operations of singeing and steeping are going on at one and the same time, which effectually prevents any accident that might otherwise arise from the effects of the hot iron.

The goods are then boiled or else bowked in a solution of potash; (some workmen prefer to have this alkali in a pure caustic state;) they are then well cleansed, by thorough washing in wash-wheels, or in stocks to ensure their being entirely divested of the alkali. The intention of thus treating them with potash, is to remove any grease or impurity that may be attached to them, which would otherwise endanger the evenness and uniformity of the colours. This process is called ASHING.

By some calico-printers it has been imagined that the rendering the lye caustic is apt to impair the texture of the cloth; and I doubt not but that this has often been the case. Under the eye of the master, however, I am sure it may be employed with advantage and safety;—with advantage, because *mild* alkali has but a slight affinity for the grease; whereas *caustic* alkali forms a real soap with any oleaginous matter, and then the compound is readily soluble in water; and though the alkali be made perfectly caustic, if the solution be sufficiently diluted, it may be used with perfect safety. A convenient mode of mixing the potash and

¹ A beautiful apparatus has lately been introduced for singeing off the nap by means of the flame from carburetted hydrogen gas, which bids fair to supersede the old system of hot iron cylinders.

² When goods are padded or blocked for a full rich colour, and printed, they may be dried in the dunged state and singed again to take off the superfluous nap left by the first dressing; the mordant is not injured in the slightest degree, and the goods are much improved,

lime, and digesting them with water so as to prepare a caustic lye, will be found described in the Essay on the fixed alkalies.

It may be remarked, that in weaving calicoes the workman generally greases the reeds, in order to make them move easier.

Wherever this grease is in the cloth, it becomes fixed by the operation of singeing; and if it be not taken out before bleaching, it will not come out afterwards by the usual process of ashing and souring: for, when the pieces are submitted to a blue vat to be dyed of a uniform self-colour, all those greasy places will be found to have taken the dye in a very imperfect manner. Tallow is also employed for dressing the warp, and this has a baneful effect on all goods which are designed for printing.

This defect in the operation of the pale blue dipping is often attended with very serious consequences, so that I know of no subject which better deserves the patient investigation of the calico-printer. I have seen a large number of pieces of printed calicoes which had all taken a solution of iron so as to form an extremely good black; also the acetate of alumina, which had formed with the madder a beautiful red; likewise the citric acid, which produced a perfect resist—and yet, when these goods came into the blue vat, certain parts of the pattern intended for blue, still remained quite white, the indigo having had no action whatever on those parts; a circumstance which is sufficient of itself to spoil the goods, and render the whole expense of printing the other colours totally lost.

To cleanse such goods previously to their being printed, various expedients have been adopted, but I apprehend nothing but a solution of caustic alkali can be depended upon. To prove the effect of any method which may be tried, it is a good way to run the pieces through water, and then to pass them from the water so gradually over a roller, as to give the superintendant an opportunity of examining every inch of the surface; and if any part remains greasy, it will be seen at once, for that part will continue dry while all the rest of the cloth is wet.

There is another way in which the goodness of bleaching might be proved. Let a few of the suspected pieces be run once or twice through a madder-copper, at the temperature of about 180° . This will inevitably mark any part that may be imperfectly bleached; whereas, if the operation has been properly performed, they will come out so little stained, that an intelligent workman, who has been used to a madder-copper, will at once be satisfied that they contain no impurity that can form a permanent mordant.

The next process in calico-printing is one with diluted sulphuric acid. A quantity of soft water having been poured into a leaden vessel, oil of vitriol is gradually added to it, in the proportion of about twenty pounds of oil of vitriol to every hundred gal-

lons of water, which by weight is in the proportion of about one to forty.

When this mixture has been well stirred, it is ready for use. Sometimes it is employed in this state, at others it is heated to 90° or upwards of Fahrenheit, according to the nature of the work to be done, and the goods are immersed in it. They are not suffered to lie in this acidulous liquor, but are wound by means of a winch over a wooden cylinder, that every part of the cloth may be successively immersed in the fluid, and every part exposed alternately to the action of the atmosphere.

This operation is generally continued for about twenty minutes, and is designed to remove any iron-moulds or other stains which the cloth may have acquired. It has also the effect of neutralizing any portion of potash that may have been left in contact with the cloth. The process is called **SOURING**.

After this operation it is necessary to wash the goods thoroughly, that no part of the acid may be left in them, to injure their texture; and this is best effected by means of the wash-wheel. The calicoes are then to be regularly and thoroughly dried, which finishes these preliminary operations, known in the trade by the term **PREPARATION**: so that those cloths which have passed through these manipulations are said to have undergone a preparation.

Besides the uses already mentioned, there is another advantage attending these processes, viz. that the cloth which has undergone this preparation will after maddering bleach or clear sooner, the colours will be brighter, and the whites more delicate, than they would have been had they not gone through these previous operations.

The next process is that of **CALENDERING**. Here the goods are passed through a set of rollers, which gives them a gloss, and the appearance of having been ironed. They are now fit for printing. But for copper-plate printing, or cylinder work, the process of calendering is omitted.

In printing fast colours, the artist usually proceeds in this way: He lays the piece of calico, which has been already smoothed by calendering, upon a strong thick table, made of a flat stone, which is previously covered with a woollen cloth. He then proceeds to apply one or more mordants, as the case may require, for fixing the intended colours. These mordants are applied by means of wooden blocks, with the patterns formed upon them. These blocks were formerly made of holly, or other hard wood, and the cutting them was a separate branch of the business. Of late years, however, a considerable improvement has been made in this department, by the introduction of brass or copper; that is, the pat-

tern, instead of being actually cut in the wood, is now formed by means of slender pieces of one of those metals being firmly fixed to the block, so as to produce the pattern intended. The pattern when thus formed with copper, is not only more lasting, but it has also the advantage of giving greater sharpness and beauty to the impression.

When it was customary to use wooden blocks, the patterns were not enched in the wood, but the wood was cut away in such a manner as to leave the pattern in relief. It will be obvious that this must always be the case in *block-printing*.

When the mordant is ready, it is mixed up either with flour-paste, or with a thick aqueous solution of gum arabic, gum senegal, or gum tragacanth.

Flour is an article of considerable consumption with the printers for making paste. Should it be musty from keeping, it is of little consequence for their use; but they are careful to buy none but such as has been made with sound wheat, for if unsound it will be of no value for their purposes, and if sour it must be used up the same day it is made; for on the next day it becomes watery and unfit for use, materially injuring the mordant. Gum tragacanth is much dearer than the other gums; but notwithstanding this, it must be had for some styles of work, as no other will answer for any of those colours or mordants which are prepared with nitrous acid. A solution of gum senegal would be coagulated in an instant by any of those preparations. Of late years an article called British gum has also been much in use for the same purpose; so much so that the making of it has become a distinct and considerable trade. It is merely common STARCH calcined till it assumes a cinnamon brown colour, and then pulverized and passed through sieves of various degrees of fineness.

When the colour has been properly mixed with flour-paste, or with a solution of either of the gums above mentioned, it is spread upon a piece of superfine woollen cloth strained tight upon a hoop.

This is placed within another hoop, covered either with sheepskin or oil-cloth. These hoops are both so broad as to give to each of them the appearance of a tambarine. That which is covered with the woollen cloth is called a *sieve*, the other a *case*. The sieve within its case is now placed in a small tub of gum-water, and is ready for use. The tub is usually 28 inches wide at top and 32 at bottom, it being of great consequence to have it wider at bottom than at top, to give the sieve and case full play when dipped upon by the printer; for were it to get fast to the sides of the tub, the surface of the sieve would be uneven.

When the apparatus is thus prepared, the mordant is applied by a brush to the surface of the sieve. This is called *TEERING*.

It should have been remarked, that when a colourless mordant, like the acetate of alumina, is employed, the colourman generally mixes a little of the decoction of Brazil wood, or of any other fugitive dye, with it, which must, however, only be done by an experienced man, or considerable mischief may ensue. This is called **SIGHTENING**; and is for the purpose of making the pattern more obvious to the workman, that he may see its progress, and the efficacy of the materials, as he proceeds in printing. The manipulation may be thus described.

Taking the block containing the pattern in one hand, the workman applies it gently to the surface of the sieve, so that a sufficient quantity of the thickened mordant may adhere to the figures. When the block is thus charged, he applies it to the calico, and gives it a blow with a small mallet, either slightly or otherwise, according to the nature of the pattern.

This alternate application of the block to the sieve and to the calico, is continued until he has gone over the whole piece. In this way several different mordants are sometimes applied to the same piece of goods. This is indeed always necessary, when the finished piece is intended to contain a variety of colours, the different colours requiring different mordants to fix them and render them permanent.

The calico, which is always perfectly dry before it leaves the printers, is now removed to a room called the hanging-room, for age, where a degree of heat seldom higher than 70° or 80° is given to it by means of flues, which go round the room on the inside near the floor. The intention of this is to evaporate the acids used in the preparation of the mordants, which might otherwise injure the texture, and also to fix the base more surely within the fibres of the cloth. It remains in this room about 24 hours when colours produced by acetate of alumina are required; but for those made from acetate of iron, as blacks, chocolates, purples, &c., it should hang five or six days to oxidize and evaporate the acids.

Whenever acetate of alumina is printed as a mordant upon calico, it appears to me that the pieces ought not to go into the hanging-room until the work has been first thoroughly dried in the open air, because it is well known that the earth of alumina is precipitated from a solution of this salt in a high temperature. I suspect this to be the cause of many of those disappointments which are perpetually occurring in the production of the various shades of yellow and madder reds.

Of late years a more convenient method has been adopted, which consists in passing the calicoes by means of machinery along a set of apparatus known by the name of *steam-chests*. These are large square cast-iron vessels fixed at some little distance from

each other, sometimes on an inclined plane, and in other cases perpendicular one above the other: they are kept constantly full of steam, and are connected with each other by bent pipes either of iron or lead. It is so contrived that the pieces of calico are made to pass over each of these heated chests in contact with their surfaces; and in consequence of the access of atmospheric air, as they pass from one of these chests to the other, they are generally found to have become thoroughly dried by the time they arrive at the end of the series.

If iron-liquor has been employed in printing the goods, it is an excellent practice to keep them for several days exposed to the atmosphere¹ after their removal from the hanging-room, as the blacks, pompadours, olives, and indeed every other colour prepared with that metal, will increase in intensity; the goods will clean better in the dung-vessels, as will be explained hereafter, and the colours will rise higher and brighter when they come into the copper of bark or madder.

It may be worth an experiment to discover whether the colours containing iron would not be better if they were suffered to be only a *very short time* in the stove, but were hung up instead for several days, exposed to a current of air at the temperature of the atmosphere; as the iron would thus acquire the oxygen slower, and consequently would be fixed more firmly in the fibres of the cloth.

When the pieces are removed from the hanging-room, they are passed, by means of a winch, through water at various temperatures, with a little cow-dung mixed in it. The intention of the dung is to absorb and remove that portion of the mordant which is not actually combined with the cloth, and which otherwise might stain the white or unprinted parts.

This part of the business was formerly conducted in a very uncleanly and negligent way; but of late years some printers have incurred a considerable expense in the construction of their dunging machines, with cocks for hot and cold water attached to them, and thermometers to regulate the temperature.

I suspect, however, that the dung of the cow is serviceable in another way besides that of cleansing, though few printers may be aware of the nature of its operation.—It is acknowledged that madder, cochineal, and some other dyes, produce much better colours on woollen than on cotton cloths, owing to the former being of animal, and the latter of vegetable origin. I presume, therefore, that the dung imparts an *animal* matter to the fibres of

¹ The iron in an acetous solution is in the state of the *black* oxide; but by exposure to the air it acquires a further dose of oxygen, and obtains the state of the *red* or peroxide.

the cotton, and that this animal matter acts as an additional mordant, and thus more powerfully attracts the colouring particles of the dye, than the mordants alone would be capable of doing.

If a piece of calico, prepared with the acetate of alumina, be divided into two parts, and the superfluous mordant removed from the one by cow-dung and water, and from the other by water only, at the same temperature, it will be found, on passing the two portions through a decoction of weld or quercitron bark, that the yellow will be much more intense and bright in that which had been submitted to the action of the cow-dung¹.

The process of DUNGING calicoes is an operation that varies in time from five to forty minutes, according to the style of the work. The pieces are then taken to the river or wheel, to be more effectually washed; and after this they are passed through tepid water, in order that the workman may be assured that every impurity is removed.

His next care is to provide a copper boiler of pure cold water, into which a sufficient quantity of madder is broken, and then a fire is lighted underneath the copper. The calicoes, printed and rinsed as above, are now put into this boiler, and from the time they are immersed, the workman never ceases to turn the winch, so as to pass every part of the goods repeatedly through the liquor, until the whole acquires a boiling heat. Indeed, this operation is sometimes continued for ten or fifteen minutes after the bath of madder actually boils, when the pieces are taken out and washed thoroughly. In most of the large calico-works, a considerable improvement in the method of madding has been adopted since the publication of the first edition of these Essays. This consists in giving a perpetual motion to the calico by means of the steam-engine. The ends of several pieces are fastened together, and then they are put into constant motion through the madder vessels, which are heated by steam, and made of wood five feet long, three feet broad, and three feet deep, this shape being more convenient than round vessels, when the motion is given to the winch by the steam-engine. The steam is let into them through two-inch copper pipes, and is regulated by a valve or stop-cock, so that they can be brought up to the boiling point, or to any degree below it, with greater regularity than can be done by fire under a copper; yet coppers are necessary for some styles of work. By these means the colours are rendered more uniform; and one man is enabled to attend to three dyeing-vessels at one time, which is found to be a great economy of labour.

Madder is one of the most valuable drugs we have, for a variety

¹ Berthollet, who analysed the dung of the cow, found in it a substance partaking of the nature of animal bile.

of purposes in dyeing and calico-printing: as it is the agent by which the best and most permanent blacks are produced; also the finest purples, and every shade of red from a pale pink to a crimson. But perhaps it may not be generally known that this article improves by age. For instance: If a quantity of madder-roots be ground, and then packed tight in a cask, so as to exclude the air, and kept thus for six months, they will dye a much better colour, and go much further, than they would have done had these roots been used as soon as they were ground.

The process which is called MADDING, has the effect of imparting all the requisite colours to the goods by means of *one* operation, which may be thus explained:

While one mordant precipitates the colouring matter of the madder to a red, another precipitates a different portion of it of a purple, another precipitates it black, and so of every possible shade, from a lilac to a black, and from a pink to a deep red.

If a portion of weld or bark be added to the madder, every shade from a brown to an orange may be produced; whereas, if weld or bark alone be employed, all colours between a dark olive and a bright lemon can be imparted to the cloth. These changes are all occasioned by the play of chemical affinities, for the knowledge of which we are indebted to the improved state of chemical science.

The only materials which are employed by the calico-printers for the production of fine yellows are the quercitron bark and the weld plant; the former is the bark of a peculiar kind of oak growing in America, the latter is the produce of our own country. The weld plant (the *reseda luteola* of Linnæus) is for the most part cultivated about Doncaster in Yorkshire. It is found, however, that nothing impoverishes the land so much; otherwise it produces a very heavy and profitable crop.

Here it may be worth remarking, that whenever it is of consequence to produce the finest yellows or more delicate lemon colour, it is necessary to dry the pieces in the open air, as the stove would not fail to injure such colours; for stove-drying has always a tendency to convert a yellow to an orange. It is also necessary to be equally careful in the operation of dunging the mordants for these pale yellows; for, should this be done at a higher temperature than 96° or 100° , their beauty will certainly be impaired. There is another advantage in this, viz., by dunging at this low temperature, the dyeing may be completed even at 110° or thereabouts, which will give a much livelier colour than where a higher temperature has been employed.

The mordants generally used in calico-printing, are acetate of iron for browns, blacks, lilacs, &c.; and acetate of alumina for all the different shades of reds and yellows.

The best method that I am acquainted with of preparing the acetate of iron for making the common black colour for calico-printing is as follows:—Take the iron liquor of its full strength, or lowered with one or two waters according to the goodness of this mordant in the first instance, and then add about $2\frac{1}{2}$ lbs of flour to every gallon of the fluid, more or less according to the goodness of the flour and the kind of work for which it may be designed. Having well incorporated the flour with the iron liquor, let the whole remain twelve hours or more. After this it is to be boiled for about half an hour, or till the whole be converted into a paste of due consistence, when it will be fit for use. The materials become better incorporated, and the colour is found to work better, by lying thus long before it is finished by boiling.

Formerly the acetate of iron was made by digesting old iron hoops in sour beer, or in very weak vinegar; but of late years it has chiefly been made with the pyroligneous acid¹, the oleaginous impurities of which tend, in some cases, to improve the mordant.

Blacks are also produced by the nitrate of iron² and gallic acid; the mixture is called chemical black. The nitrate of iron is made by dissolving metallic iron in a peculiar kind of aqua-fortis. Common aqua-fortis will not answer for this purpose; for, though it may dissolve the iron with rapidity, part of the metal is apt very soon to precipitate; which not only weakens the colour, but leaves the remainder so acidulous that there is always a danger of such a preparation injuring the texture of the cloth.

Chemical black is made by mixing a decoction of galls with the nitrate of iron just described; this produces gallate of iron, and probably some tannate of that metal: the disengaged nitrous acid then dissolves the two newly formed salts. The colour called chemical black may therefore more properly be said to be an union of the colouring matter of galls with the per-oxide of iron, than a mixture of gallic acid with nitrate of iron. The gallic acid is probably like the pyroligneous, or nothing but the acetous acid holding a peculiar vegetable substance in solution; and either the muriate or the sulphate of iron, if applied to cloth in conjunction with the colouring matter of galls, will in time produce as

¹ If wood be submitted to an intense heat, when inclosed in an iron vessel of any kind with a proper aperture to allow the vapour to pass, this vapour on being condensed forms the acid in question, and is now known to be a kind of impure *vinegar*. The wood in this case is converted into *charcoal*, of which a great deal is prepared by this process, particularly for the formation of gunpowder.

² Nitrate of iron was not applied to calico-printing till within the last fifty years. This discovery formed an important æra in the trade, as it afforded the manufacturer the means of varying his styles of work in a multiplicity of ways and forms, which till then were entirely unknown.

intense and durable a black as the nitrate; but the difficulty of thickening the solutions of these salts, and the time which is required to convert their base into a per-oxide, render them less fit for the calico-printer's purpose.

It is, however, necessary to remark that the black which is formed by this solution of iron, is produced in a different way from blacks in general; for, when common iron liquor is used for this purpose, it is first printed on the calico; and when it has been sufficiently oxidized by exposure to the air, the goods are boiled in a decoction of madder, which renders such parts as had been printed with the acetate of iron an intense black. But the black from nitrate of iron and galls is applied at once to the cloth, and is not afterwards increased in intensity, or raised, as it is termed, by dyeing.

The calico-printer by using a black ready formed is thus enabled to mix it with other colours, in cases where by dyeing alone it could not be produced, as in conjunction with yellows and olives, raised by weld or quercitron bark.

The acetate of alumina is prepared by a mixture of the sulphate of alumina and potash with acetate of lead, both in a state of solution; so that, on the theory of double decomposition, sulphate of lead is formed, which precipitates, while the acetate of alumina remains in solution.

Since the demand for this article has been increased on account of the extension of the printing-trade, it has been prepared from the pyroligneous acid, by means of lime and alum. The following is the method:

The pyroligneous acid is first passed through a still, to divest it of a portion of the oil or tar which is always dissolved in it; it is then saturated with lime or whiting; and lastly, the acetate of lime thus formed, is decomposed by a heated solution of sulphate of alumina and potash. The result of this double decomposition are sulphate of lime, which precipitates, and acetate of alumina, which is drawn from the sediment of the calcareous sulphate, and preserved for use.

In reverting to the remaining processes of the print-work, it must be noticed, that when the goods have passed through the weld or madder copper, they are usually carried to a boiler containing wheat-bran and water, in which they are winched for a considerable time, for the purpose of freeing the white grounds from the stain which they had acquired from the madder or the weld. This process always impairs, in some measure, the intensity of the colours; but it is a necessary operation, as there is no other mode so convenient for removing the stain which is always given to the white part of the print by the madder, the bark, or the weld, which has been used in dyeing it.

Branning has also the effect of giving a pink hue to all madder reds. But it is not generally known what a peculiar richness may be imparted to madder colours, by raising them with a mixture of bran and madder; that is, by mixing a portion of bran with the madder in the first instance. I have myself sometimes produced colours in this way whose brilliancy has astonished me.

This mode of dyeing red with a mixture of bran and madder is called in the trade *Growse's* or London pink, and was invented by a journeyman calico-printer near London, of the name of Growse, who sold the recipe for 100 guineas. In this process the acid of the bran prevents the precipitation of the *fawn-coloured* particles of the madder, and the red produced is consequently more rosy and pure.

Madder contains two distinct species of colouring particles, a beautiful red or rose colour and a degraded yellow or fawn colour—both are precipitated on the cloth, in the usual dyeing process, to the great injury of the *tint* obtained. The object of the tedious Turkey-red process is to fix the red colouring particles so firmly as to allow the fawn-coloured ones to be dissolved and discharged by long boiling in solution of soap or soda, by chloride of soda or by acid solutions of tin. A dilute super-sulphate of potash has lately been used with success for this purpose in France.

It frequently is the case, however, that goods will not bear to be sufficiently branned to clear the whites entirely by that one operation¹; such goods, therefore, are partially cleansed in the branning-copper, and are then either laid on the grass for some days, until they become perfectly clean and white, or immersed for a certain length of time in a very weak solution of print-clearing powder; which is chloride of lime mixed with about one-tenth part of its weight of carbonate of soda.

This simple process, which effects in a few minutes what would require more than as many days in grass-bleaching, is now generally practised, and has nearly superseded crofting altogether. This is a most important improvement, as some of the large printers formerly required as much land to spread out their goods upon, as would make a farm of a very considerable size.

Besides the kinds of calico-printing already mentioned, there are others which it will be proper to notice in this place. Of these, what is called resist-work is now done in considerable quantities. It is conducted in the following manner:

¹ The temperature at which the operation of branning is performed, is very important. If bark yellows are dyed at 100°, it is customary to bran such goods at 115° or 120°, as it is a principle always to bran at a higher temperature than the goods are dyed at. Madder-work must be branned at a boiling heat.

A preparation of sulphate of copper, mixed either with flour-paste, with gum, or with pipe-clay and gum, is printed on the calico, in any shape or of any pattern that may be desired. When this is sufficiently dry, the goods are repeatedly dipped in the blue vat till they have acquired that depth of tint which may be required. The art of making an indigo-vat, or blue-vat as it is sometimes called, consists in forming such a mixture of lime and sulphate of iron as shall most effectually deoxidize the indigo; as indigo has no affinity for cloth in its natural or oxygenized state. Hence, those parts of a piece which are printed with a solution of copper will never be dyed blue in one of these vats; because the deoxidized indigo becomes oxygenated the moment it touches the copper, which parts with its oxygen to the indigo, and occasions it to become insoluble, and consequently incapable of forming a dye.

Thus, while sulphate of iron has the power of deoxidizing indigo, sulphate of copper, or any other salt of that metal, is incapable of retaining its oxygen, whenever it comes in contact with that singular substance in a state of deoxidizement; and it is a curious instance of the different degree of intensity by which oxygen is held by the different metals.

I suspect, however, there is often great waste in the management of these vats, and that the contents are often thrown away long before the indigo is spent, in consequence of the want of a due admixture of the lime and the sulphate of iron with the colouring matter; whereas, if a dyer or calico-printer be acquainted with chemical science, he will understand the nature of the operation of these substances upon each other, and hence can be at no loss how to keep up the vat to its original strength, by replenishing it occasionally with one or other of the ingredients as may be required.

The fact is, that indigo, unless it be deoxidized, is insoluble either in the alkalies or the alkaline earths; but when this is effected by the iron of the copperas, the lime dissolves it, and forms it into a perfect solution of indigo. At first a portion of the lime abstracts the sulphuric acid from the copperas, and precipitates with it in the state of sulphate of lime. The detached metal being now in the state of the protoxide of iron, and having in that stage of its oxidizement a great affinity for oxygen, it takes it from the indigo, and thus becomes changed to the per-oxide of iron, which being insoluble precipitates likewise. Thus the acid and the base of the sulphate of iron are at length both precipitated, when the remaining portion of lime seizes the deoxidized indigo and forms with it the solution desired. When the principle of the blue-vat is thus properly understood, it is an easy thing for the manager

at any time to discover which of the three materials is deficient, and to add it accordingly. I am the more desirous of offering these remarks, because I have many times heard the proprietors of a manufactory declare that they have occasionally thrown away the whole contents of a new vat, containing many pounds worth of indigo, because the foreman or manager of the works had not observed the due proportions of the lime and the copperas to put the indigo into a proper state for working; and they have an idea, that if it is once wrong it must be always so, and therefore they throw it away without attempting to correct the error.

To revert to the process of resist-work, it is necessary to say, that when the pieces have been sufficiently immersed in the blue-vat and have been washed and passed through diluted sulphuric acid, those parts which had been printed with the preparation of copper, are found to be preserved a good white; the preparation having effectually resisted the operation of the indigo, though all the other parts of the cloth have received a permanent dye. The various deep blue calicoes with white spots or white figures, which are now so common, are generally done in this way; and by a similar management with subsequent dyeing in madder, in weld or quercitron bark, figures in red or yellow (as the case may be) are exhibited upon a blue ground.

In some particular styles of work the operation of certain colours is resisted by means of stopping out with wax; but this is too expensive a method to be adopted often, in these times, when it is the object of every manufacturer to finish his prints at the least possible expense. Formerly this mode was very generally practised, and is still used in the East Indies for preserving the whites.

In printing those silk handkerchiefs called Bandanas, a process called waxing is still followed. It consists in making a preparation of tallow and rosin very liquid by heat, and in printing it in that state with a block upon the silk. When such goods are passed through the blue-vat, those parts which are covered with the tallow and rosin are preserved from the action of the indigo, and remain white, while all the rest is dyed a fast blue. The method afterwards taken to discharge a part of this blue, and produce yellow, orange, &c., will be mentioned hereafter.

A very singular-looking substance was discovered a few years ago near Stockport, which being handed about from one to another, created considerable interest in that neighbourhood. Every body supposing it to be a natural production, specimens of it were sent to a variety of persons into various parts of the kingdom, for their opinion and analysis, and among others a portion was sent to myself. However, after every one had been busily

engaged in examination and conjecture, respecting this unknown substance, it was announced, that some seventy or eighty years before, a calico-work had stood on the spot where the article was found, and that this was nothing more than a large heap of the refuse compound of flour, wax, and gum, above mentioned.

The reader will perceive that these *resists* are employed for the purpose of preserving certain parts of a piece white, and of giving other varieties to those goods in which blue is the predominant colour: but if the ground is to be white, and the piece is only to have one small object in indigo blue, such as a single sprig, then a different management is necessary, and the colour is imparted by a process which is called *pencil-blue*.

Here the indigo is deoxidized by means of orpiment, which is a sulphuret of arsenic; and formerly, whatever objects were done with it were put in by means of a pencil: hence its name, PENCIL-BLUE.

Pencil-blue is composed of the following ingredients, viz. Ten ounces of indigo finely ground in water; twenty ounces of quicklime in lumps; the same quantity of potash of commerce, or the impure sub-carbonate of this alkali; and ten ounces of orpiment. These proportions require one gallon of water, and when the whole has been properly mixed, and time has been allowed for the sediment to subside, the clear colour is to be carefully poured off and thickened with gum senegal.

The intention in using this preparation had always been to impart it to the calico, before the indigo had time to recover its oxygen: hence a small quantity only was mixed at once, or no more than could be penciled on in a very short time; but the inconvenience which attended this plan, gave rise at length to an invention which has nearly superseded the use of the pencil.

The invention to which I refer is the spring-sieve, which may be thus described:—A fine canvass sieve is suspended within a tub of pencil-blue colour, so contrived that the canvass should be in contact with the colour, and follow it as it wasted. But as the colour was consumed, the sieve did not always exactly sink with it, which occasioned great uncertainty, and sometimes considerable disappointment from the admission of too much atmospheric air:—to obviate these inconveniences many schemes were resorted to, but none of them completely answered the purpose.

This utensil has, however, now been much improved by a particular friend of mine, who has kindly allowed me to give a plate¹ and description of it; and I doubt not that I shall have the thanks of some of the manufacturers of printed cottons for having made

¹ See the plate on calico-printing, fig. 11.

public an invention of so much utility and ingenuity. It may be thus described:

A is the box which contains the colour; B is the sieve which floats within the colour; C. C. C. C. are the four springs which keep the canvass of the sieve close down upon the dissolved indigo; and D is a vessel from which the blue-tub is constantly supplied with colour, as the same is exhausted by the printer, and is upon the principle of a common bird-fountain¹. The improvement chiefly consists in the addition of this vessel, which in the beginning is completely filled with the prepared indigo, and closely corked and sealed, to prevent the possibility of the access of any atmospheric air.

Another kind of process remains to be noticed, called **CHEMICAL-DISCHARGE** work. Here the cloth is first dyed of some uniform colour, by means of a mixture of iron-liquor, and some one or more of the common vegetable dyeing substances; and calicoes thus prepared are said to be dyed of self-colours. They are then washed and dried; and when properly pressed or calendered, they are fit for receiving any pattern whatever, according to the taste or design of the artist.

This is generally effected by means of the mineral acids, which are previously prepared for the purpose, by dissolving in them a portion of one or more of the metals, according to the nature of the dye which is intended to be discharged, or of the colour to be produced. In doing this, care is taken that the discharging liquor be made so as to be capable of dissolving the iron which is contained in the dye, and which is always used in such quantity as to cover, or at least to disguise in a great measure, the other colour or colours which had been employed with it, and at the same time to act as a mordant in beautifying and fixing those colours.

Thus a piece treated with a decoction of Brazil-wood, and dyed black by being padded² with iron-liquor, if, when dried, it be printed with a peculiar solution of tin, the ferruginous portion of the dye will be dissolved, and the printed part will instantly be converted from a deep black to a brilliant crimson.

In the same way an olive-coloured calico, dyed in a solution of iron and a decoction of weld, will as quickly be changed to a pale bright yellow; and the various drabs and slates of every shade

¹ The stop-cock, which is placed in the tube, is to prevent any loss of colour, in case the barrel should by any accident admit atmospheric air, and cause the box to overflow.

² By the term *padding* is understood the operation of passing the pieces from a roller through a trough containing a solution of iron, or any other mordant. *Blotching* is another term used in calico-printing, and is nearly synonymous with padding.

which have iron in their composition, will undergo as sudden a change by the same treatment; though the colour of the figures produced on them will depend on the materials with which the cloths were originally dyed. Even the deepest gold colours, or strongest buffs, if produced by iron only, may, by a peculiar preparation of tin, be discharged; and such parts of the cloth as have been treated with this metallic solution will be restored to their pristine whiteness.

By similar management, calicoes dyed of a light blue in the indigo-vat, then run through sumach and copperas, and finished in a bath of quercitron bark and alum, may have figures of a bright green imparted to them. Here the green is originally formed by means of the indigo-vat and the bark, though it is enveloped by the iron of the copperas, which overcomes the other colours, till the solution of tin is applied, which removes the iron from those particular parts, and gives a brilliancy to the remaining colours which they would not otherwise have possessed; the tin being a powerful mordant for the bark, by which the yellow of the green is produced.

Again, a good self-colour may be given to calicoes, merely by dyeing them in sumach and copperas, and then running them through an alkaline solution of annotto; and here the figures produced by the application of a colourless solution of tin will be of a bright orange. But it is needless to enumerate more instances, as the workman accustomed to a dye-house will have little difficulty in varying these in a thousand ways, when he becomes acquainted with the nature of the solution of tin which he employs.

The whole of this, however, refers to that branch of discharge-work only, where all the purposes are attained by dissolving the iron which makes a part of the colour that is intended to be discharged; whereas, the finer and more expensive work is done in a different way, and by a process which it will be necessary for me presently to describe.

It is, however, proper to remark, that there is an objection to the particular kind of chemical discharge-work of which I have been speaking, namely, that it is not perfectly fast; that is, the goods produced in this way will not bear such frequent washing, as those which are done by the bath of madder or bark.

It is certainly an object of great national importance to give a permanency and beauty to the calico-printing of the country; and a great deal of very excellent printing is now done in various parts of the kingdom, especially for the best chintz-work and other furniture patterns. But, in what is called fast-work, there is a great variety of qualities, and some of it little deserves the name of permanent.

The mention of permanent colours reminds me of a very valuable GREEN which was invented some years ago by a Mr. Islet of London, and which deserves to be noticed in this Essay. This colour is produced by printing ground indigo mixed with a peculiar kind of solution of tin, and in then fastening the indigo within the fibres of the calico by means of that process, which is well known to printers by the technical designation of *china-blue dipping*¹. After this the goods are dyed in a copper of bark or weld, which converts the blue to a green, and the whites are afterwards cleansed by croft-bleaching, &c.

There is another mode of producing very beautiful blues which has been much practised lately, and therefore deserves notice. This consists in printing some solution of iron, and then passing the goods through a very dilute and neutral solution of prussiate of potash. The prussian blue which is thus formed upon the cloth may be rendered tolerably permanent by a variety of expedients, and this by means of any of the yellow dyes may afterwards be formed to any shade of green or of olive.

Begging to be excused for the irregularity of these digressions, I must not forget to revert to that other kind of discharge-work which I have engaged to describe, and which I will now attempt as concisely as is consistent with perspicuity and correctness.

Here, the agent which is employed is the citric acid, and this is used in various states of concentration according to the purpose to which it is to be applied, and the strength of the ground intended to be discharged. It is chiefly employed for the production of white figures upon self-coloured grounds produced by madder and sundry other dyes. For this intention the acid, in whatever state of concentration it may be, is mixed with either gum or with flour-paste² to a proper consistency for the block, the plate, or the cylinder, and thence it is transferred to the piece; and wherever it attaches, the mordant, whether iron or alumine, is discharged, and a delicate white arises in its stead³.

The acid here referred to is produced from the juice of limes or lemons, and formerly it was not employed by the calico-printer

¹ China-blue is produced thus:—Indigo ground fine, and then thickened, is printed upon the cloth, and afterwards it is dissolved, and chemically united to the fabric, by alternate immersion in a solution of sulphate of iron and in lime water.

² When citric acid is used for resist-work, it is always mixed with gum senegal and pipe-clay. The clay gives it a greater body, and likewise acts mechanically as a resister.

³ It should be understood, that the discharge is printed upon the mordants before the goods are dyed. In using citric acid for this purpose, a portion of one of the mineral acids is sometimes mixed with it.

until it had been reduced to the utmost point of concentration⁴ and appeared in a crystalline form. Even then, it was not thought sufficiently pure, but was dissolved again, and redissolved and recrystallized, until it became as white and pellucid as any other pure salt in a crystallized state, and was then generally sold for 36s. the pound, at which high price it could only be employed on the best styles of work. Now, however, it is oftener used in the brown, or first state of crystallization; and some of the larger printers purchase lime juice, and concentrate it themselves; and in many cases they use it largely both for discharge- and resist-work, without crystallizing it⁴. More on this subject may be seen in the Essay on Citric Acid, which was written with the hope of rendering an essential service to a large body of manufacturers in various parts of these kingdoms.

This mention of discharge-work by citric acid⁵ reminds me of another species of discharge, which is employed by the printers of Bandana handkerchiefs, and which I am under the promise of noticing before I conclude this Essay.

The agent which these printers employ is the nitrous, and sometimes the nitro-muriatic acid. It is used for the purpose of putting yellow figures upon blue silk handkerchiefs. The following is the process which is principally adopted.

Aqua-fortis, or nitro-muriatic acid, of such a strength as is suitable for the kind of blue which is intended to be discharged, is mixed either with gum tragacanth, or with flour-paste, to a proper consistence, and in this form it is printed on the silk, by means of a common block, on which the intended pattern is cut. The consequence of this is, that wherever the acid attaches, there the original colour is discharged, and a yellow dye is produced in its place. The pieces are then steamed, by passing them over a vessel containing boiling water, which gives brilliancy to the colour and finishes the operation.

If a stronger dye than the usual yellow, or even a deep orange be desired, all that is necessary is to immerse the goods, for a moment, in lime water, or in a solution of lime and potash; and by varying the proportions of these ingredients a great variety of shades may be produced.

It must be noticed that this method is applicable only to the

⁴ Since Mr. Parkes published the last edition of these Essays, the use of crystallized citric acid has been entirely abandoned: concentrated juice is quite sufficient, and it is now frequently imported at 45 to 50 degrees of Ronchetti's citrometer. — EDIT.

⁵ Mr. Thomson, a scientific printer, who has an establishment near Clithero, which is carried on under the firm of Thomson and Chippendale, has taken out a patent for discharging the Turkey-red dye by means of the citric acid and chlorine; and the work executed in this way has a very pleasing effect.

discharge of the colour from *silk* handkerchiefs ; the process for producing the spots on *cotton* Bandanas being entirely different. This manufacture, which is of considerably more importance than the former, was established some years ago in Scotland, for the purpose of producing imitations of the Bandana handkerchiefs which are imported from India. It is conducted in the following manner.

Pieces of fine calico are dyed by the Turkey-red process, of a colour as nearly approaching to scarlet as can be produced on cotton by that means ; and, upon this plain dyed calico, white spots are produced by a method to be described hereafter. The pieces of calico having been bleached to a perfect white before they are dyed Turkey-red, the present object is, not only to discharge the dye on certain parts of the cloth, but by the same agent to restore those parts to their original whiteness.

These discharged parts are usually in the form of spots, sometimes round and sometimes square or triangular, and these marks or spots are produced by the action of a chemical liquid, while the pieces of calico are under the action of a powerful press. The machinery for this purpose is made in an expensive manner, as it is required to be of very great strength, and it is put together with the utmost exactness.

To this press two horizontal plates are adapted, for the purpose of receiving the calico which is to be placed between them. The pattern intended to be given to the handkerchiefs is first marked upon these plates ; and in the bottom plate, holes are cut of the exact form and size of the intended spots ; whereas, in the upper plate every spot is marked out by a small copper tube which goes through the plate and is firmly cemented within it.

When the plates are about to be fixed, there is a contrivance for ascertaining that the orifices of the tubes in the upper plate are exactly perpendicular to the respective holes in the under plate ; which is a circumstance of the utmost importance, as the discharging liquor which is poured into the tubes is designed to pass through the folds of calico into the corresponding holes in the lower plate.

The apparatus being thus prepared, the handkerchief pieces are neatly folded into squares of the size of a single handkerchief and of the thickness of about ten or a dozen folds. One of these pieces, consisting of ten or twelve handkerchiefs, is then laid smoothly upon the lower plate, and is so disposed as to lie square with the plate. By means of a lever, the cover of the press, to which the upper plate is attached, is then lowered, and by continuing the action of the lever, these plates, with the folds of calico between them, are screwed firmly together.

The consequence of this is, that the ends of the tubes fixed in

the upper plate, are brought to press upon the surface of the cloth; and as these are made to press upon it with great force, and as each tube has a corresponding hole immediately beneath it in the under plate, it is evident that the fluid which is poured into these tubes will be directed into the holes below, and cannot pass in any other direction.

When things are thus arranged, and the press is firmly screwed down, a very dilute solution of chloride of lime, containing a small portion of sulphuric acid, is poured upon the upper plate of the press; and as this plate has an iron rim round its upper surface, the fluid which is poured upon it is determined into the tubes, and as it percolates through the cloth, it discharges the colour on those particular parts, and passes off through the holes of the lower plate into a trough placed underneath to receive it.

It is observable that the chemical liquid is prepared sufficiently strong to discharge the colour in the course of about ten or twelve minutes, and yet not so powerful as to endanger the fabric of the cloth; and that the great pressure of the screw prevents the fluid from spreading beyond the precise limits marked out by the tubes and the corresponding holes underneath.

As soon as the discharging liquor is found to have entirely passed through, the press is slackened, and the cloth is removed to make room for another piece, which is immediately substituted; and in this way the process is continued throughout the day without interruption. One press, requiring the attention of two men only, will print fifty pieces, containing one dozen handkerchiefs each, in the course of the day.

When the pieces are first taken from the press, the spots which have been produced by the discharging liquid are not perfectly white; it is therefore necessary to have recourse to a subsequent process similar to the one usually employed for clearing the whites on common printed calicoes; and this not only removes every stain, but also heightens the brightness of the Turkey-red dye. I am aware that at one time there was a general complaint of such handkerchiefs, after frequent washings, becoming tender in those parts which had been acted upon by the chemical liquor: this I think must be owing either to the employment of a liquor too much concentrated, or to the remains of the acid not having been perfectly removed before the goods were dried and pressed for sale; as I am persuaded that with due caution the process may be safely conducted.

When speaking of yellows, it was my intention to have mentioned, that there is a mode of producing yellows on calico which is not very frequently practised, and yet has a very good effect. The process is as follows:

A strong decoction of quercitron bark, thickened with gum

tragacanth, is to be mixed with a portion of very pure muriate of tin, and this, when printed with the usual management, will produce a colour of great brightness and durability. I mention this the rather, because very many pleasing effects may be obtained by this method which cannot be produced in the usual way, by means of the acetate of alumina, and any of the yellow dyes that may be employed with it.

There is one very important advantage which this mode possesses, viz. that should it be necessary to pad a piece in diluted acetate of alumina to obtain a pale lemon ground, the yellow figures, previously imparted by the above process, will not give out any part of their colour to the second mordant; whereas, whenever a strong yellow has been produced in the common way, the pattern is very apt to spread and become irregular, and oftentimes to stain the white ground, when the piece comes a second time into the acetate of alumina.

The most expensive kind of calico-printing called *CHINTZ-WORK* still remains to be described. The term *chintz-work* is descriptive of that kind of calico-printing which is employed for window-curtains and other furniture, and it differs more in the richness and variety of the colours, than in any other circumstance.

In relating the processes by which these beautiful prints are produced, I shall suppose the calico to be already properly bleached and smoothed ready to receive the impressions of the block. The first thing then to attend to, is to apply the mordant for the colour which is intended to be imparted in the first instance. Thus, if a black be designed, a mordant of acetate of iron, commonly called iron-liquor, is thickened with gum, and printed upon the cloth in any pattern that may have been selected for the purpose. If this same mordant be diluted with water, it will form a proper mordant for a purple; and the same, still further diluted, will, when it comes into the dyeing-copper, form a lilac. In this way, all the varieties of shades from a pale lilac to a strong purple, and from a purple to a black, may be produced by acetate of iron diluted with various portions of water, and then dyed with madder.

In like manner, a colourless solution of acetate of alumina thickened with gum or flour-paste, forms a mordant for dark red; if diluted with water, it makes a common red; and by diluting it further and further, every shade of pink may be produced. Again, by the admixture of acetate of iron and acetate of alumina, a mordant for chocolate colours, maroons, &c., is formed, either approaching to the purple or the red, according to the admixture; that is, according to the proportion of either of these original mordants which may predominate in the mixture.

When these several mordants have been printed upon the calico, they are allowed to hang for age, in a warm room for three or four days, as described page 536; they then go through the operation of dunging, which consists in rinsing them in warm water in which a little cow-dung is diffused, as has been already described. When the pieces are sufficiently dunged, which is not the case till all the superabundant mordants are removed, they are well washed in clean water, and then boiled in a decoction of madder, until the madder-bath is exhausted. In consequence of different mordants having been applied to the cloth, this one boiling in the madder-liquor will at once produce all the colours above mentioned. When the pieces are thus dyed, they are to be rinsed in cold water, and rendered perfectly white by exposure to the air, or by print-clearing powder as already described.

The processes which have now been detailed, will produce what is called *common chintz-work*; but if it be desired to make the goods still richer by the addition of yellows, bright olives, drabs, &c. the cloth must undergo another series of operations, which may be thus described:

Upon those parts of the calico which still remain white, any of the above mordants may be printed, according to the effect designed to be produced; after which, all the preceding managements are to be repeated, except that instead of boiling in a decoction of madder, they are to be immersed for about half an hour, more or less, in a warm decoction of quercitron bark, (the *Quercus nigra* of Linnæus,) a most important dye-wood, introduced by Dr. Bancroft, and which is found to give out a much brighter colour to *tepid* water than it does when treated with *boiling* water, or with water nearly approaching to that temperature.

The effect produced upon these prints by an immersion in a lukewarm decoction of this American bark, will be quite different from that produced by the madder; upon those parts of the cloth where the mordants have been printed which before produced a black, a dark olive only will be apparent; and instead of pompadours will be drabs; and instead of reds we shall have yellows, which will vary in intensity according to the strength of the aluminous mordant.

Again: a further variety may be given to these prints, if the yellow mordant, or acetate of alumina, be applied to any of the colours which have already been dyed with madder; but this must be done before the pieces are immersed in the decoction of bark. This application will convert the reds and pinks into different shades of oranges, and the lilacs into cinnamon colours. By means of these different processes, an endless variety may be given to the goods, and a calico-printer of taste will never be at a

loss how to produce a pleasing effect, whatever may be the patterns which he has to imprint upon the cloth. This second immersion in the dyeing vessel will, however, give a yellow tinge to the remainder of the whites, but a short exposure on the grass will obliterate it.

When chintz-furniture prints are designed to have as much variety of colouring as possible, a part of the remaining white is often coloured blue or green, or of any shade between those colours, by a still different process. This is done with what is called pencil-blue, which is a preparation that has already been described. The blue is given by putting in the prepared indigo with a pencil; and the green is produced by pencilling some of the same colour over certain parts of the pattern which has already been dyed yellow.

When these colours have been imparted, the printing is said to be finished, and the pieces are hung up to dry for at least twenty-four hours; after which they are rinsed thoroughly in cold water; and when they have been dried with care, they are properly calendered and put up for sale. For the purpose of drying finished goods, an excellent apparatus has been invented, consisting of an arrangement of cylinders made of tinned iron or copper filled with steam, and round which the calico is made to pass in succession, as shown at figure 10 of the plate on calico-printing. In this apparatus there is a vane fixed underneath every two of these cylinders, which is moved by means of the steam-engine, and agitates the air so as to very much facilitate the drying process. This mode of drying printed calicoes is so effectual, that although the cloth be wound from the heap marked C upon the first cylinder quite in a wet state, it becomes thoroughly dry by the time it has passed over the whole of the apparatus, and falls in a perfect state on the heap marked D; all which will be better understood by a reference to the plate.

Nothing now remains but to notice an improvement which has been made of late years by the introduction of CYLINDER-PRINTING, which has the advantage of superior accuracy and neatness, as well as of great expedition.

The plate which accompanies this Essay will afford a general idea of the nature of the expensive machines which are employed for this purpose; the construction of which may be thus further explained: They are so contrived that the cylinders on which the patterns are engraved, furnish themselves with the prepared colour during their revolutions; their surfaces are kept clean by a steel knife, or *doctor* as it is called, passing over them the moment they have charged themselves with the thickened colour; and they have such a pressure given to them, either by means of screws or levers, which can be tightened or slackened at pleasure,

CHEMICAL ESSAYS

Plate 11

Fig. 11



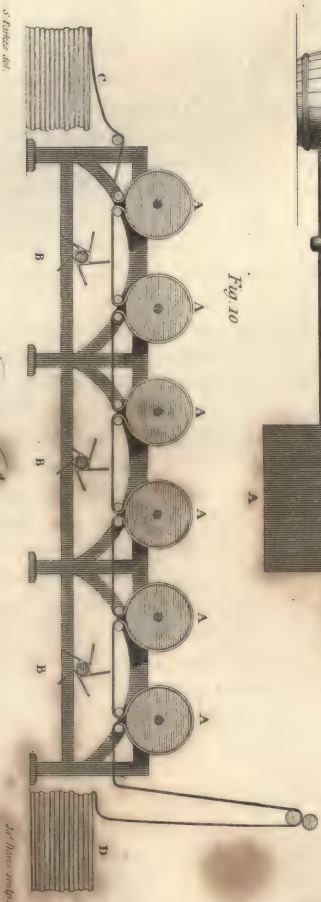
Fig. 12

A. Colours, Sheds
B. The Force
C. Spring for the
D. Blue Ink



Fig. 10.
A. Steam Engine
B. Shovel, Trench
C. Lamp, Candle
D. Small Pipe

Fig. 10



35 Inches high.

24 Inches wide.

Candle Spring



that the whole cylinder is made to deposit its colouring matter with the greatest certainty and exactness on the cloth, while this rolls over it in succession, from one end of the piece to the other.

These cylinders, which are made of copper, are from twenty-eight to forty-two inches in length, according to the width of the calico to be printed, and four to five inches in diameter; and these massy rollers have the patterns enched upon their surfaces, in the same way as a pattern is cut upon a flat plate of copper, that is intended to be employed in copper-plate printing¹.

Many of these machines are contrived so as to carry two of these cylinders, each of which has a trough of colour attached to it, by which means two different colours may be printed on the same calico at one and the same time; and Mr. Adam Parkinson of Manchester has invented a machine capable of printing at one time, by means of one cylinder and two surface rollers, or by two of the former and one of the latter, three distinct colours. See Plates, fig. 12.

These machines have not only the excellence of printing more correctly than can possibly be done by means of the block, but the saving of time and labour which they afford is great indeed. A piece of calico which would take a man and a boy one hour and a half to print with one colour, or three hours to finish with two colours, may by this means be printed in three minutes and a half, and the work will be much more completely done than could even have been imagined before the introduction of this invention.

Besides these cylinders there are others which are called *SURFACE-MACHINES*, which contain cylinders, not of copper but of wood, and which have the pattern formed upon their surfaces in relief exactly similar to the blocks described in page 534. These are employed in particular styles, especially on light grounds, and for certain kinds of resist- and discharge-work.

It must be obvious to every one who is acquainted with the subject, what an astonishing facility these machines must have afforded to the production of printed calicoes; and also what an advantage they give to the British printer in foreign markets.

During the few years which have elapsed since the publication of this Essay and the death of its author, so important have been the discoveries and improvements in the art of calico-printing,

¹ As these cylinders were formerly made with plates of copper hammered into a circular form and joined by brazing, great loss was sometimes sustained by the engraving giving way upon the brazed joint. To obviate this, a patent was obtained for boring the copper cylinder from the solid metal in the modern way of boring cannon.

that I, as editor, should be justly censured for leaving it incomplete, were I not to enumerate and briefly describe them. This I think it preferable to do by an addition to the Essay, rather than to interweave my remarks in the text of the author. The invention most decidedly new in every respect, and the most important, as to the great extent to which it has been carried, is that system of printing which is known by the name of steam-colours.

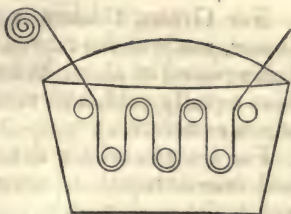
A steam-colour is simply colouring-matter permanently fixed upon cloth by means of steam: it is usually a decoction extracted from vegetable substances by hot water, printed upon a cloth, prepared for its reception, by being previously passed through a certain mordant commonly called oxymuriate of tin. This mordant is however in reality a very strong solution of nitromuriate, or, what is preferable, of muriate of tin, the metal being converted into a perfect peroxide by the sudden addition of nitric acid, which acting with a violent effervescence, is decomposed, leaving one portion of its oxygen with the tin, thereby converting it from the state of a protoxide to that of a peroxide, and the nitrous acid flying away in the form of gas.

After printing, the colours are rendered brighter, deeper, and faster, by being exposed to the action of steam, as will be presently described; and they are much improved by one or two nights' age both before and after steaming. Mineral acids are in general too active, and when combined with tin are apt to injure the cloth; on this account it is usual to prepare the cloth with an alkaline solution of tin, and then to print the colouring-matter with a vegetable acid and an aluminous mordant. Alum may however be employed, though its acid is mineral.

I shall first describe the preparations of the cloth, which may be done either with an acid, or an alkaline solution of tin, the latter however being preferable for all colours excepting Prussian blue. In 10 gallons of water dissolve 15lbs of potash and $7\frac{1}{2}$ lbs of fallen lime:—boil for fifteen minutes, then add 1 oz. of very finely ground litharge; stir well, and let the sediment subside. Pour off the clear liquor, wash the sediment repeatedly, till by the addition of the washings you have reduced the liquor to 20° of Twaddell's hydrometer, or 1·100¹. When it is cool, add one gallon of the oxymuriate of tin at 120° or 1·600, to 14 gallons of the caustic alkali. With this liquor pad your pieces, taking care not to dry them entirely, but finish the drying them over three or four drums of the drying machine, (Vide plate 6, fig. 10.)

¹ When I mention degrees of specific gravity during this Essay, I wish to be always understood to take those of Twaddell's hydrometer, that being the instrument universally employed by the Lancashire calico-printers.

Let the machine at the same time roll them to the number of 15 pieces on each roll, and keep them warm with blankets. Have in readiness a tub holding from 150 to 200 gallons of water, in which dissolve 6 oz. of sal ammoniac per gallon. Run the pieces through this liquor at the rate of a minute and a half to each piece, with rollers after this manner; then wash them well and dry.



The pieces should always be tubbed off the same day on which they have been padded, and whilst they are warm from the drying machine. For every 15 pieces passed through the sal-ammoniac tub, you add, well stirring all the time, one gill of sulphuric acid, and when filling up your tub, always put 6 oz. of sal-ammoniac to every gallon of water you pour in. It is of great importance to the success of the work, that the alkaline solution should not precipitate whilst padding; and to prevent this, keep it well stirred in the trough, and let a regular supply of liquor be kept up. The cloth thus prepared will keep for any length of time, and the tin is so firmly combined with it that no process will take it out; so that the pieces are rendered quite useless for any other purpose than steam colours.

You now print the colours on the cloth by machines. (Vide plate 5.) A few examples of the methods of preparing the principal colours will suffice. For Cochineal Pink, add five pounds of ground cochineal, in a copper pan *tinned inside*, to three gallons of distilled water; scald it for an hour at a heat of 200° Fahrenheit, taking care not to let it boil; pour off the liquor, and to the cochineal add $1\frac{1}{2}$ gallon of fresh water; BOIL this for an hour to extract the whole of the colour, repeating the operation with half a gallon of water if necessary. Put all the liquors together, and evaporate them down to three gallons.

Take seven pints of this liquor and one pint of acetate of alumina (made with 4lbs of alum and $4\frac{1}{2}$ lbs of white sugar of lead), thicken with starch, and when boiled add 4 ounces of oxalic acid, cooling the colour as soon as possible; for the more quickly that is effected the better. Print the pieces and hang them up for one night, steam them twenty minutes, hang them one night more, then rinse them in clean water, wash, and finish.

For Blue, dissolve in one gallon of cold water $1\frac{1}{4}$ lb of Tartaric acid, to which add $1\frac{1}{4}$ lb of prussiate of potash; thicken the clear liquor with starch, taking care to cool the colour as quickly as possible. Print, hang and steam as for the pink; but the more age you give the blue after steaming, the richer will be the colour.

For Green, thicken with starch one gallon of Persian berry liquor, made at the rate of two pounds of berries per gallon, and half a pound of alum. When cold, add one gallon of the thickened blue equally cold, and mix them well together. Print, hang and steam as before.

For Purple, take a decoction of logwood, at 10° of Twaddell, add one-sixteenth of acetate of iron, and treat this in the same way as the cochineal.

For Yellow, take best Persian berries eight or ten ounces to the gallon of water, boil them until all the colouring matter is extracted, add eight ounces of alum to the gallon, thicken with flour and British gum.

For Orange, take one measure of the cochineal liquor, and as many of the above yellow as will produce the shade required; thicken with starch, and when cool add four ounces of oxalic acid to each gallon.

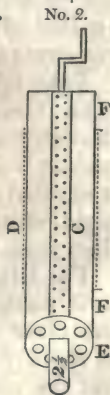
Brown, Cinnamons, &c. are made merely by a mixture of pink, yellow, and purple, or of purple and yellow to any shade that fancy may dictate, and are then treated as above.

The cloth being prepared and the colours printed on it, as we have just described, all that remains to be explained is the apparatus for steaming; a sketch of which will be found in the annexed cuts, having the tin part coloured *red*, and the copper *black*.

No. 1.—The steam-guage. A two-inch iron pipe A is brought from the boiler to a convenient room, near to the steam, rising ten or twelve inches above the floor. On this is placed a copper two-inch pipe B with a stop-cock in the middle of it, and a cone eight inches by five on the upper part with a mouth one inch and a quarter wide.



No. 2.—The cylinder. The middle tube C is made of strong copper, brought through the lower end of the cylinder six inches; it is two inches and a half in diameter, and thirty-eight inches long, pierced full of holes about the size of a pea, and an inch apart from each other. Over this is a tin cylinder D, nine inches in diameter, leaving of course all round a space of three inches and a quarter. It is thirty-two inches long, soldered in the copper at both ends, and also pierced full of small holes, a quarter of an inch apart, to the breadth of twenty-seven inches, leaving a part at each end F F without holes. At the lower end are six or seven holes, E, to let out the water produced from the steam, and to the upper end is an affixed iron handle for the purpose of winding on the pieces.



The printed pieces, ten or fifteen at a time, are wound upon the

tin cylinder on three or four folds of blanket. The apparatus is then placed upright on the cone B, which it fits firmly, and is supported by a hoop at the top. The steam is turned on by means of the stop-cock, and passing up the tube C fills the space between the tube and the tin cylinder, and forcing itself through the small holes, into the pieces, penetrates the whole mass and escapes¹. After the calicoes have been exposed to the action of the steam for twenty minutes, it is turned off, the apparatus taken down, the pieces removed, and ten or fifteen more rolled on in their room. Where much work is done, it is necessary to have three or four of these cylinders, and one or two of larger dimensions for wide calicoes. During these manipulations, it is of the utmost importance that *iron* should not in any shape be allowed to touch the cloth, otherwise the colours would be certainly spoiled; copper and tin, it will be observed, are used for every part of the apparatus.

When the prints are removed from the steamer, they are quite wet, and so hot that it is difficult to touch them, but they are pulled off with great rapidity, and on exposure to the air are instantly dry; they are then sent to the hanging-room to age, which completes the operation.

The improvement next in importance to steam colours, which I deem it necessary to describe, is a certain course of *resist-work*², technically called *neutral*, which can be performed with all the colours of a chintz, viz., black, three shades of red, and purple, and dipped blue. These colours are all block work excepting *white* and *black*, which can be done by a machine: the method of doing them is as follows:—The first block is printed with a paste made of a solution of citric acid at 16°, eight or ten ounces of sulphate of copper per gallon, British gum, and a little pipe-clay. This is the *white* or *neutral* resist³.

The second block is a paste made of acetate of alumina at 14° added to one-fourth part of nitrate of zinc, or sulphate of copper, with British gum and a little soft soap. This is the *red* resist, which for paler shades of red is diluted with gum senegal. The third block is a paste made of acetate of iron and *flour* for *blacks*.

The fourth block, if a lilac is introduced, is acetate of iron at 4°, and nitrate of zinc with gum senegal or British gum, as may do best for the pattern, diluted for paler shades.

¹ Three or four folds of blanket between the tin cylinder and the pieces are necessary to absorb moisture. The same quantity must be applied to the outside of the pieces, otherwise the last piece would not get its due proportion of steam.

² For the description of resist-work see pages 542 to 545.

³ It may at first appear extraordinary to speak of any other than a *white* resist; but it will be noticed that they all four act as perfectly white resists in the indigo blue vat; it is afterwards in the madder-copper that the first only is in

These are all printed one after the other on the calicoes, which are then hung up in a *cool room* for two or three days, after which they are taken and dipped blue in a *neutral vat*¹, which is usually set with one hundred pounds of good indigo; the pieces are not hooked on a frame, but passed through the vat in one minute and a half for each piece, by means of rollers up and down, after the same manner as the sal-ammoniac tub, described page 557. Twenty or twenty-five pieces are fastened end to end by a wire, and by this method they can be run through in less time than five could be hooked on a frame. They are now taken to the wash wheel and washed twice, then dunged and maddered in the method usually employed for madder goods, and afterwards yellowed with *berry yellow*, as *bark yellow* is apt to injure the scarlet ground.

This style of work was first produced about the year 1805, and has sold more extensively than any print that ever came out. It is not necessary for the printer to confine himself to red, black, or blue grounds, as they can be varied to any shade of orange, olive, &c., by the addition of quercitron bark to the madder. In the notes to the second volume of Dr. Ure's translation of Berthollet On the Art of Dyeing, this style is described under the name of "*Lapis*," but the description is not quite correct: in fact, when Berthollet wrote that work, neither the French nor Swiss knew how to do them; but the printers at Mulhausen and Ghent have since executed them in a beautiful manner, and sold them under the name of "*Lapis*."

For *best work* in madder-grounds, viz., chocolate, black or scarlet, it is necessary to pass the goods twice through the madder-baths or coppers. If for instance fifty pounds of madder are required to dye ten pieces, thirty pounds of it are taken for first dyeing in cold water, and the pieces turned in it till the liquor arrives at 190° in two hours or two and a quarter; they are then taken out and washed; this is called the *scald*, after which they are entered again with the remaining twenty pounds of madder into cold water, turned as before, and brought up to the boiling point in two hours and a half: they should remain in the boiling liquor five, ten, or fifteen minutes, as may be required, and afterwards be well washed and branned.

It has lately been discovered that the prussiate of potash of commerce, being in reality the ferro-prussiate, contains a sufficiency of iron to produce a beautiful madder purple, without em-

reality a resist, and the remaining three are mordants to produce three different colours from one madder-bath.

¹ *Neutral vat* is merely the technical term for the indigo vat employed in *neutral resist-work*. Mr. Parkes gives a detailed account of the method of setting an indigo vat in the preceding part of the Essay, pages 543 and 544. The neutral vat is usually set in the first instance with one hundred pounds of

ploying any acetate or other solution of iron whatever. The process is, to dissolve one pound of prussiate of potash and one pound of tartaric acid in a gallon of water; thicken the clear liquor with starch, and then print the pattern on the calico with your cylinder in the usual manner; hang the pieces after printing, for one night, then steam them for ten or fifteen minutes, and afterwards hang them for another night. Pass them now through a *cold* and *clear* chloride of lime pit, upon a roller frame, in a minute and a half; wash them well, and then run them for fifteen minutes through water heated to 120° or 130° of Fahrenheit. Wash afterwards, dye them as other maddered goods, bran, white, and lastly croft or clear them. This is a very fast colour, and can be executed to any shade required.

The next material improvement in madder colours left for me to describe, and which, to be understood thoroughly, will require considerable minuteness of detail, is that beautiful addition to our previously known colours, chrome yellow on madder grounds. It will be necessary first to explain the process required for the preparation of the cloth.

To one gallon of Gallipoli oil, add twelve gallons of water with four ounces of pearlash dissolved in each gallon; pad your pieces with this liquor five times successively, dry them each time over the flue, and then hang them in a warm room for thirty-six hours; take care to stir the liquor whilst padding.

First steep.—Prepare a clean vessel of water with one ounce of pearlash dissolved in each gallon; warm it to 115° or 120° , enter the pieces, pushing them well over head in the liquor, and cover them up with blankets for nine hours; skim the liquor before they are taken out, to prevent any dirt from adhering to the cloth; squeeze them as dry as possible, but let no water touch them.

Second steep.—Set the vessel again with pearlash liquor, and proceed in every respect as with the first, calculating about two gallons of liquor to each piece.

well ground indigo: for the first working of the vat one hundred and forty pounds of lime and one hundred pounds of copperas are put in the night before it is worked; afterwards the quantities may be regulated by the number of pieces to be done on the following day. When the vat is new, sixty or eighty pieces may be dipped on the first day, then add ten pounds of lime and eight pounds of copperas and dip sixty or eighty more, and let the vat rest one day. After it has dipped five hundred pieces it becomes too weak for neutrals, and is set apart for more common or paler shades of blue; if for the latter, it is yet strong enough to dip many hundreds. A neutral or any blue vat for best work may be used *warm*, and heated to about 80° by passing a steam pipe along the bottom; but this is not absolutely necessary, excepting in cold weather, though some houses work all their vats warm for dark blues and neutrals. It is necessary to have three or four of these neutral vats.

Third steep.—Proceed exactly as with the first and second; but it is now necessary to squeeze the pieces, then to wash them well, and to dry them in a warm stove; on the next day put them into a clean bath of hot water at 170° for fifteen minutes; repeat this three times, drying and washing between each bath; they will now be quite fit for printing: and we shall describe the process of rainbow shades, as they are called, a beautiful style of printing, now become very common.

For Red, take acetate of alumina at 10° (No. 1) and thicken with gum senegal for darkest or first shade; then take one measure of No. 1, and add ten measures of gum water for second shade; and one measure of the same (No. 1) and twenty of gum water for third shade, and so on, reducing the original standard (No. 1) by ten measures of gum water for every lighter shade.

For Purples, use acetate of iron in the same way as acetate of alumina for reds, and the admixture of these two mordants will give chocolate shades. The reds and purples are all printed at the same time with one dip of the block: the block is a plain surface covered with cloth; the shades are spread upon a sieve by means of a brush, the block is then accurately dipped upon it and placed on the piece. I shall not attempt to describe the various modes which are adopted for spreading the mordants on the sieve, as scarcely two printers use the same method.

After printing, the goods must hang in a warm room for three or four days at the least, or more if convenient. DUNG them over rollers in liquor heated to 160° , pass a piece per minute, and then wash them well.

Branning.—Set a vessel rich with bran, boil it for five minutes, cool it down to 160° , then turn the pieces in it for ten minutes, and wash them well.

Dyeing.—Take for a dyeing of ten pieces, two pounds of glue, and allow seven pounds of fine old crop madder for each piece. Commence with *cold water*, heating it gradually during the first hour to 125° , during the second to 180° , and in a quarter of an hour afterwards to the boiling point. Boil them fifteen minutes, making in the whole two hours and a half; then wash them well and squeeze them.

Tubbing after dyeing.—Pour one quart of aquafortis at 32° of Twaddell into a tub of fifty gallons of water. Turn five pieces over a winch in this for ten minutes, let them then be well washed and squeezed. Add now a gill more of the acid, and turn five other pieces; after thirty pieces are thus tubbed, pour off the liquor and re-set the tub with fresh acid and water, as at first, proceeding in the same manner with any quantity of goods that may be required; they must all at last be *twice* well washed in the wheel.

Clearing.—Boil two hundred and fifty gallons of water in a

clean vessel, and whilst boiling dissolve in it twenty pounds of white soap; enter ten pieces, and turn them for fifteen minutes at an easy boil. Wash them well, and the madder dyeing will be entirely completed.

To put a pattern of chrome yellow on the above red or purple shades, take one gallon of nitrate of lead, five pounds of tartaric acid dissolved in cold water, thickened, if you print with the block, with British gum and pipe-clay; but if you use the cylinder machines, it will be necessary to use British gum only. After printing, hang the pieces in a warm room for two or three hours.

Discharging.—Having a vat ready prepared of a solution of chloride of lime with excess of lime in water, standing at 10° or 12° of Twaddell and heated to 80° , let the pieces be hooked on to a dipping frame, and previous to their immersion, let the vat be raked up till the liquor appears quite white. Dip your frame in and keep it gently in motion for four or five minutes, then rinse the pieces immediately in cold water over the winch, and afterwards wash them well.—The only process now remaining will be

Chroming.—In a clean tub, with a winch over it, holding thirty or forty gallons of cold water, dissolve two ounces of bichromate of potash to every gallon of water. Into this solution enter the pieces, two at a time, over the winch, and turn them for fifteen minutes, or till the yellow is sufficiently bright.

The alkaline preparation of the cloth for these rainbow shades will also answer for plain ground Turkey-reds, if the padding and steeping are well managed. For aluming and galling pieces for plain reds, they may be either tubbed or padded, as best suits the convenience of the party doing them.

All goods that are to be discharged for chrome yellows must undergo the oil preparation, or the chloride of lime will materially injure all the colours where it is not intended that they should be acted upon.

There is another style of chrome yellows which varies a little from the one which has just been described with such minuteness; but in this also it is absolutely necessary to use prepared cloth. The red mordant is acetate of alumina at 14° , dunged, and dyed full red, branned and cleared; the drab is then printed on by means of prussiate of potash and tartaric acid in equal quantities, steamed twenty minutes, washed and dried.

The pattern by block is then printed in nitrate of lead and tartaric acid, after which it is dipped in a warm chloride of lime vat, which converts the prussiate of potash stripe to a drab, excepting where the tartaric acid and nitrate of lead have prevented it.

It is now taken to the chrome tub and raised, when the lead on the red becomes instantly yellow, and that on the drab green,

having the appearance of being printed with two different blocks, whereas only one has in reality been employed.

This is an exquisitely beautiful operation, and gives so many ideas as to what it is possible to effect, that there really seem no bounds to the varied tints that may be produced whenever a renovation in the state of trade shall give the spirited printer some hope of reimbursement for the time, talents, and capital which he must necessarily employ in pushing this elegant style of work into the various ramifications of which it is capable.

I have lying by my side, whilst writing, specimens of this and of every other style which I have described, and wish it were possible to give coloured plates of them, as they would tend materially to elucidate the several processes; but I fear it will be found impracticable.

Another excellent colour has been lately invented, and has been produced in very large quantities; I allude to the brown from sulphate of manganese. The process is as follows: Reduce the solution of sulphate of manganese to 15° (it is usually sold at 50°), pad the pieces over a warm flue, and hang them in a cool room twenty-four hours; pass them then through caustic lye at 14° , and afterwards through hot water for a few minutes; wash and dry them.

Discharge.—For the white, take muriate of tin 120° and thicken with starch. For yellow, take nitrate of lead at 70° , muriate of tin 120° , and starch. For blue, prussiate of potash, muriate of tin, a little nitrate of iron, and thicken with saloup. For pink, a strong decoction of Brazil wood, with two ounces of muriatic acid per gallon, thickened with gum tragacanth, then add one quart of muriate of tin 120° to three quarts of colour; wash, dry, and finish.

For brown *objects* on *white* grounds, dissolve two pounds and a half of brown salt (sulphate of manganese *in powder*) in one gallon of water, to which add two pounds of sugar of lead and half a pound of sulphate of iron; stir well for three hours, and then let all subside; thicken with gum senegal, and add a quarter of a gill of Gallipoli oil to prevent it from frothing. Print the pieces, and hang them for twenty-four hours, then pad them with caustic lye at 12° over a cold flue, and wash well; pass them through a *clear* chloride of lime vat at 4° in three or four minutes, then wash again, squeeze, and finish. If the pieces can be laid on the grass in the open air for an hour or two, it will much improve their colour; the sulphate of iron is merely to give an olive brown; without it, a reddish brown will arise, and iron liquor will produce another shade.

A common red mordant from machine work may be steamed ten minutes the same day it is printed, and then hung one night;

this management causes the mordant to penetrate the cloth, and brings up the finest stippled work of the engraving. Chocolate may be proceeded with exactly in the same way; but in all cases it must be recollected that as a portion of the mordant is carried off by the steam, it is necessary to use it stronger than you would if it were not steamed. A purple produced from iron liquor will not do steamed, but one from prussiate of potash, as described pages 560 and 561, will be much improved thereby.

Considering that an Essay on calico-printing would be incomplete, without some detail of the process for dyeing Turkey-red, I applied to Mr. John Thompson, of Glasgow, a highly esteemed friend of Mr. Parkes, who is probably at least as well acquainted with both its theory and practice as any individual in Great Britain. For the former he refers me to a paper which he published in the *Annals of Philosophy*, vol. viii. page 463, and which he says he has since seen no reason to deviate from. With respect to the latter, he states that he can add nothing to the process with which he furnished Dr. Ure, and which was published in the notes to his translation of Berthollet, excepting he were to give a practical detail of the manipulations, which differ at the various manufactories, and which would fill a volume. He kindly allows me to copy both, which I will therefore do in his own words. The process which he adopts for one hundred weight of cloth or yarn is as follows:

“1st. Boil the goods with white soap and pearlash, or soda ley. Twelve pounds of white soap are dissolved in water in a copper, along with six gallons of the ley, pretty strong; the boiling is continued for five or six hours.

“2nd. *The sheep's-dung liquor*.—To make this, take twelve gallons of soda liquor No. 3 (sp. gr. 1.015), two gallons Gallipoli oil, six gallons sheep's-dung, twenty-four gallons soda liquor No. 5 (sp. gr. 1.025).

“Tramp the cloth or yarn well in this liquor, then hang it in the air to dry, and next in the stove. This dunging is repeated a second and a third time as above, drying the goods after each repetition.

“The yarn or cloth is to be steeped all night in warm water at 100° Fahr., with four gallons of soda liquor No. 12 (sp. gr. 1.060). Out of this, it is to be well wrung next morning, hung in the air, and lastly dried in the stove.

“Take now twelve gallons of weak soda liquor No. 3 (sp. gr. 1.015), Gallipoli oil two gallons, soda liquor No. 5 (sp. gr. 1.025), thirty gallons; tramp the cloth or yarn in this mixture three or four times, then put in the air, and finish in the stove every time.

Steep for clearing away the Oil.

“Steep the goods in warm water at 140° Fahr. with four gallons of soda liquor for each cwt., wring it out next morning, wash well and dry it; when it is ready for the galls.

Gall Liquor.

“Take twenty-four or twenty-five pounds of nut-galls, and boil them for eight hours; take the clear liquor and tramp the cloth or yarn as warm through this liquor as the skin can bear; wring, put in the air, and then in the stove.

Alum Liquor.

“Take twenty-five pounds of alum, dissolve in warm water, add four gallons of soda No. 12 (sp. gr. 1.060); next morning take the clear liquor, put it into a copper, and warm it as hot as the hands can bear; tramp the stuff through this liquor, wring, and put in the stove to dry.

Second Aluming as above.

“Steep the alumed goods in luke-warm water all night, next day wash them well in the river; then they are ready for drying.

To dye twelve dozen of Cloths (pieces).

“Allow two pounds of madder to each pound of cloth, bring it to the boiling point in an hour, and keep boiling for half an hour; then enter the goods into the copper, adding two gallons of blood well mixed; let the goods be now well washed and dried. For the *cue*, take half soda and half pearlashes, half a gallon of oil, and as much water as will bring the liquor to No. 6 of the hydrometer (sp. gr. 1.030), but the oil must have been previously mixed with twelve gallons of soda liquor No. 3 (sp. gr. 1.015). Put the goods through this liquor as through the white bath; wring, and stove-dry.

For Clearing.

“Fill a copper with clean water; dissolve four or five pounds of white soap in it, and half a pound of pearlashes; boil slowly from six to eight hours, then wash and wring the goods. Lastly, fill a copper with clean water, adding a pound or two of white soap, and boil the goods an hour or two. They are now finished.”

Having thus given Mr. Thompson's account of his method of dyeing Turkey-red, I cannot do better then transcribe his very ingenious and satisfactory opinions as to a theory which from the first period of its introduction to the present day has probably more puzzled scientific men than any other application of chemistry to the arts. Indeed so long ago as 1794, Dr. Bancroft said that “it is an unaccountable process that chemical analysis does not elucidate.”

“Silk and worsted,” says Mr. Thompson, “have a natural varnish which cotton does not possess. To supply this defect, the repeated immersions, followed by exposure to the atmosphere and to the heated air of a stove, may give the oil the proper consistency, by the absorption of oxygen, for forming a varnish, with which the colouring matter unites, and through which it may be said to shine, which causes that superior brilliancy which the goods attain when they are cleared, or, as it may be called, polished. I therefore presume that the fixedness and brilliancy of the colour will depend on the quantity of oil imbibed, as every repetition of drying presents new fibres to be varnished with an additional quantity; for I have always found that the permanency was in proportion to the number of manipulations in the saponaceous liquor, and a proportionable freedom could also be used in reducing or clearing. The white immersions, omitting the sheep’s-dung, are just applying successive coats of varnish. Clearing is never attempted from the madder-copper, without immersing the goods again in soda and oil, and drying them in a stove, which I consider to be also supplying them with an additional coat.

“The alkaline ley occasions a greater separation in the particles of the oil, by which it combines more closely with the fabric of the cloth. The sheep’s-dung in the first immersions may serve as a covering or great coat, to keep the goods moist for a considerable time, that they may more fully imbibe the liquor, by preventing the evaporation from being too quick in the great heat to which they are exposed.

“After the frequent immersions the cloth feels like leather, no doubt from a superfluity of liquor. It is then steeped in a ley of carbonate of soda, and afterwards well washed and dried, as a preparation for the galling and aluming. The astringent principle has been long known for darkening and fixing common red colours on cotton, by uniting with the earth of alum, and strengthening the basis. To the use of blood in the madder-copper I attribute nothing; as in the rancid and putrid state in which I have seen it used, were it not for the prejudice of the operator, it might be safely dispensed with.

“In proof of the above idea, that it is only the oil uniting with the earth of alum that is of use, I may refer to the mode of dyeing that colour in the East, quoted by Dr. Bancroft, viz. soaking their cotton in oil (no matter of what description) during the night, and exposing it to the sun and air during the day, for seven successive days, rinsing it only in running water, and then immersing it in a decoction of galls and the leaves of sumach previous to aluming.

“I would therefore request the practical dyer, who wishes to arrive at a knowledge of this unaccountable process, to give up

the idea of animalization, if by it be meant impregnating the cloth with an animal matter, and by the power of the microscope, or any better method, look for the whole truth from some other source than chemical analysis. I am at present inclined to believe that it is a mechanical operation united to a chemical, and that the frequent immersions in the imperfect soap are equivalent to laying on the first, second, third, &c. coats preparatory to finishing a fine painting in oil."

The operations with the Turkey-red most particularly connected with calico-printing are, First, the discharging process by means of perforated plates, which will be found particularly described by Mr. Parkes in the preceding part of this Essay, pages 550—551. Secondly, the methods of discharging the Turkey-red, and supplying its place with other colours, as detailed at great length in the specification of the patent granted to James Thompson, Esq. of Clitheroe, in 1813. The object of this patent was to discharge certain parts of the cloth, which had been dyed Turkey-red, white, and afterwards to print those white parts of any colours required, by the usual methods. This, Mr. Thompson effected by first printing upon the cloth some vegetable acid, metallic oxide, or acidulous salt, which had a stronger affinity for lime than chlorine has, so that it would speedily decompose chloride of lime or bleaching powder; he preferred a mixture of supersulphate of potash with citric or tartaric acid: when this was printed upon the cloth to the required pattern, and *dried*, he immersed the cloth in a solution of chloride of lime; the acid immediately seized upon and combined with the lime, thereby disengaging the chlorine, which instantly deprived of their colour those parts of the cloth which had been printed with the acid. He thus describes his usual process:—

First, he thickens in the usual way with starch, a gallon of pure acetic acid, mixed whilst hot with five pounds of crystallised tartaric acid; or sometimes, instead of this, he thickens in the same way a gallon of concentrated lemon juice (or two pounds and a half of citric acid dissolved in a gallon of water), with two pounds of supersulphate of potash added to it whilst hot.

Secondly, he prints on the Turkey-red cloth this paste in the usual way.

Thirdly, he immerses the cloths when *dry* in a solution of bleaching powder (sp. gr. 1.050), by hooking them on to a frame called a dipping-frame, such as is used in dyeing indigo, taking care that no two folds of the cloth touch each other, and keeps them constantly moving in this liquor for five or ten minutes. He then washes, brans, clears, and applies other colours according to the usual methods employed by calico-printers.

In the year 1815, Mr. Thompson took out another patent for

an improved process, by which he did not merely discharge the original colour to a white, and then by a subsequent process applied other colours in the white spaces, but at once and by the same operation he discharged the colour (be what it might, excepting only Turkey-red), and at the same time applied a metallic oxide or earthy base, which was itself a colour, or served as a mordant to some colour to be afterwards produced.

His process was to print upon those parts of the cloth, which he wished to deprive of one colour and to receive another, some earthy or metallic salt, the acid of which, having a greater affinity for lime than chlorine has, will disengage the chlorine; and the metallic or earthy base being deposited upon the cloth, will either be itself a colour, or will act as a mordant to some other colour. The cloth is then passed through the solution of bleaching powder, as before described, washed, and the mordant (which may be a salt of alumina, iron, tin, or copper, according to the colour or colours wanted) is raised according to the usual operations of dyeing. If for instance a yellow figure or stripe be wanted, acetate of alumina is printed upon the cloth, which then passes through the bleaching liquor, and is afterwards raised by quercitron bark or other yellow dye; and by the use of various mordants great varieties of colours and shades may be obtained.

My additions to this Essay have extended further than I at first contemplated; but so great have been the changes and improvements since it was first published, that I considered it to be incumbent upon me to give a brief summary of them: and calico-printing being an art entirely dependent upon chemistry, I have no doubt that it will continue, as it has hitherto done, to advance as rapidly as the science from whence it derives its very being.—EDIT.

APPENDIX.

ADDITIONAL NOTES.

NOTES TO ESSAY I.

1. *Invention of printing.*—Page 1, line 4.

“WE have a fact established beyond controversy, that WILLIAM CAXTON, an eminent mercer and negotiator, first introduced the art of printing with *fusible* types into England; and some suppose that Frederick Corsellis, or some other foreigner, used *wooden* types a few years before him. He was succeeded by Wynkyn de Worde, who improved the art very much, and first introduced musical notes, and (some think) Roman numerals: but the Roman character was first used in printing by Pynson, who was by extraction a Norman. The progress of the typographic art among us was very rapid. Margaret, Duchess of Somerset, or more properly Countess of Richmond and Derby, took it under her patronage, and Pynson had a formal appointment to the office of king's printer, in the beginning of the reign of her grandson Henry VIII.”—Herbert's *Preface to Ames's Typographic al Antiquities*. The first book known to be printed in England was by Caxton in the year 1474. The first by his successor, Wynkyn de Worde, appeared in 1494.

“The storied pyramid, the laurelled bust,
The trophied arch, had crumbled into dust;
The sacred symbol, and the epic song,
(Unknown the character, forgot the tongue,)
Till to astonish'd realms Papyra taught
To paint in mystic colours Sound and Thought,
With Wisdom's voice to print the page sublime,
And mark in adamant the steps of Time.”

2. *The alchemists.*—Page 1, line 9.

The following proclamation respecting two noted alchemists was published by King Edward III. A.D. 1329. “Know all men, that we have been assured, that John Rows and Mr. William de Dalby know how to

make silver by the art of alchymy; that they have made it in former times, and still continue to make it; and considering that these men by their art, and by making that precious metal, may be profitable to us, and to our kingdom, we have commanded our well-beloved Thomas Cary to apprehend the foresaid John and William wherever they can be found, within liberties or without, and bring them to us, together with all the instruments of their art, under safe and sure custody."—Rymer's *Fœdera*, tom. iv. pag. 384.

So lately as the year 1784, Dr. James Price, F.R.S. of London, attempted to revive the spirit of alchemy. He produced a red and a white powder, with which he boasted that he could convert mercury into gold or silver. He made several experiments before a number of respectable persons; but when the powders were exhausted, and he was importuned on all sides to renew his powders and repeat his experiments, before men of science, he swallowed laurel water and put an end to his existence.—Crell's *Chemical Annals*, 1784.

3. Soap waste.—Page 4, line 39.

The use of soapers' ashes as a manure, was known more than 200 years ago, though it is a commonly received opinion that its application to this purpose is a modern invention. In Platt's *Jewel House of Art and Nature*, 4to, London, 1594, page 77, is a wood-print engraving of an ear of corn that was produced from a field which had been enriched with this manure. The writer of the work also states that a good mortar for building may be made by a mixture of two loads of such ashes, one of lime, one of loam, and one of Woolwich sand. He says that just before he wrote, a soap-boiler at Aldgate built a large house for his own family with such mortar, in order to encourage others to buy soap-ashes for the same purpose.

4. Metallic oxides.—Page 5, line 26.

In the beginning of the 17th century, *Jean Rey*, a physician at Perigord, published a work, which is now extremely rare, to prove that the increase which metals acquire in calcination arises from the air. An apothecary at Bergerac having informed him that two pounds of fine tin, during six hours calcination, had increased seven ounces in weight, he answers, "This increase of weight proceeds from the air, which mixes with the calx, and attaches itself to its minutest particles, in the same manner as water adheres, and adds weight, to those of sand."—See *Rosier's Journal*, tom. v. Paris, 1777. This writer surely discovers great sagacity for the time in which he lived; for he must have preceded Mayow nearly half a century, whose celebrated *Tractatus quinque* were not published till the year 1674. A copy of Rey's book was lately discovered in Paris, and an English translation of it has lately been printed in the *Journal of Science, Literature, and the Arts*.

5. The blood.—Page 6, line 11.

The source of the iron in animal blood is very mysterious; for it is well known that the quantity may be increased either by medicine or exercise. "In hard-working people," says Mr. Johnson, "the red particles abound; and by the exercise of particular parts, the same takes place, as

in the wings of those birds accustomed to fly, and in the legs of those accustomed to walk a great deal."—Johnson's *Animal Chemistry*, vol. i. page 42.

6. *Morocco leather*.—Page 13, line 1.

The manufacture of Russia leather is not thoroughly understood in England. The best account of the process hitherto published, is in Tooke's *View of the Russian Empire*, 8vo, London, 1799, vol. iii. page 514. A respectable tanner in the North of England informed me that there is more of the tanning principle in the root of the common plant called *Burnet*, the *Sanguisorba* of Linnæus, than in oak bark. It is a plant that bears a red flower, and was, a century ago, the clover of the day. He thinks it might be cultivated for cattle, as they are all fond of it; and that it might be plowed up every three years in order to collect together the roots for the purpose of tanning.

7. *Intense light*.—Page 15, line 28.

It is so important to obtain an intense light at the public light-houses, that great expense has been incurred in the construction of reflectors of silver. It has occurred to me that *strontites* and some other substances might be employed to make coloured lights for greater distinction in hazy nights or foggy weather. If moisture be present in the mixture of strontites with inflammable bodies, the flame will be of the colour of carmine. Thus, if any of the salts of this earth be dissolved in alcohol, the spirit will burn with a flame of this colour. In like manner the flame of any of the salts of barytes, under similar treatment, will produce a brilliant yellow flame, and boracic acid a flame of a beautiful green colour. It has long been known that strontites, barytes, and boracic acid, will produce these colours, but I have not heard of their being used for this purpose.

8. *Scientific brewer*.—Page 16, line 34.

Since this edition went to press, the 57th and 60th numbers of the "Library of Useful Knowledge" have appeared, containing the very best and most scientific treatise on "*The Art of Brewing*" that has ever been laid before the public; who are, I believe, indebted for it to the able pen of Mr. David Booth, author of the "*Analytical Dictionary of the English Language*," and other works.

Its perusal will materially assist every person who has a wish to understand the subject either theoretically or practically: he will find a detailed account of the process in all its parts, accompanied with drawings of the utensils and apparatus, a description of the necessary philosophical instruments, of the ingredients allowed by law to be used, and of the illegal ingredients, distinguishing those which are wholesome, and which if allowed would be improvements, from those which are deleterious, and employed only by worthless and unprincipled brewers. All the needful manipulations are minutely detailed, as is also a process by which raw grain may be used as a substitute for malt, or rather may be converted into malt in the mashing tub instead of the malting floor. Although this important discovery may be employed by private families who brew at home, the absurd prohibitions of the Legislature prevent not

only this but any other improvement from being adopted by the public brewer whilst the present code of excise laws remains in existence.

This writer has also invented an improved saccharometer, which to private families in particular will prove of inestimable advantage; effectually preventing the uncertainty and disappointment now so frequently experienced by those who brew at home, in the quality and strength of their ale, arising from variations in the goodness of the malt and other causes. For a particular description of this valuable instrument, which no family ought to be without, who in brewing their own beer are not regardless of economy and careless of quality, I must refer the reader to a pamphlet, entitled "*Description and Use of the Brewer's Saccharometer, &c. &c.*" sold, together with the instrument, by Baldwin and Cradock. Price two guineas.—EDIT.

9. *Sugar*.—Page 17, line 41.

Sugar is said to contain more nutriment in a given bulk than any other known substance. For this and other reasons it would be a proper article, when corn is scarce, for feeding cattle, if Government would remit the duties. In consequence of such an intention having been entertained, (in the summer of the year 1808,) I underwent several examinations by a committee of the house of commons, and at their request undertook a series of experiments upon sugar, and also drew up a memoir on the subject, which the committee ordered to be printed, accompanied with their own remarks, for the use of the members of the house. As this memoir contains a variety of new experiments on the nature of sugar, and several curious facts not generally known, I embrace this opportunity of referring to the paper, which will be found in the *fourth Report of the Honourable the West India Committee to the House of Commons*, and also in the *Philosophical Magazine*, where it was reprinted in September of the same year.

10. *Zinc*.—Page 18, line 29.

I would recommend it to those who have occasion for large quantities of hydrogen-gas to use zinc instead of iron; it not only produces a purer gas, but the sulphate of zinc (white vitriol) that results from the process would indemnify the operator for his expense in purchasing the materials; whereas, when iron is used, the residuum is of little value.

Hellot speaks of the deleterious powers of zinc, but I do not know that any other writer has considered this metal to be poisonous. A few years ago a mine of zinc-ore was discovered on Lord Ribblesdale's estate at Craven in Yorkshire. This ore is found there in a state of such purity as to have been sold as a substitute for white lead in painting. In the year 1805, Messrs. Hobson and Silvester of Sheffield obtained a patent for a method of manufacturing zinc into wire, also into vessels of capacity, and into rolled plates for a variety of purposes. Zinc is a brittle metal at the temperature of the atmosphere; but these gentlemen discovered that when it is heated to 220°, and from that to 300°, it becomes malleable, and capable of enduring the rolling press or the hammer.

11. *Black-ash*.—Page 19, line 11.

Black-ash is prepared by the following process. The waste lye which

is pumped out of the boiler of the soap manufacturer, is evaporated in large pans of wrought iron, until the salt separates from it, which is removed as it precipitates. These salts, usually consisting of the sulphate, muriate and sebate of soda and potash, are then taken to a reverberatory furnace, where they undergo a heat sufficient to melt and partially decompose them; and when they are in a state of pasty fusion a hole is opened in the side of the furnace, through which the matter flows into an iron pan placed underneath to receive it. This saline mixture, freed from much of its impurity by the process, becomes a ponderous and solid mass as it cools, and in this state it is sold again to the soap-boiler for the manufacture of common yellow soap.

12. *Salt-petre*.—Page 20, line 1.

Salt-petre might probably be made to considerable advantage in certain situations in Great Britain. Wherever stables or cow-houses are so situated that the floors, on one or more of the sides, are considerably above the surface of the ground, an abundant efflorescence of salt-petre will generally be found between the joinings of the bricks, it being formed from the urine of the cattle, assisted by the combined action of the air and the lime of the mortar used in the construction of the buildings. A particular account of the method of collecting and crystallizing salt-petre in the East Indies will be found in the *Philosophical Transactions for 1665*, p. 103.

A most interesting detail of the methods by which a very extraordinary collection of salt-petre was formed throughout the several provinces of France, in a case of great emergency, is printed in the *Tradesman, or Commercial Magazine*, vol. ii. p. 533.

NOTES TO ESSAY II.

13. *Enlarging its bulk*.—Page 30, line 24.

The expansive force of water when in the act of freezing is a curious subject. Many interesting particulars will be found in Mr. Boyle's work already quoted, in pages 86, 90, 204, &c. A modern traveller has also noted the following circumstances which occurred in Canada in the winter of 1806 or 1807. "Experiments," says he, "have been made on iron shells, by military men, to ascertain the expansion of freezing water. After having nearly filled the shells with water, iron plugs were strongly driven in at the fuse-hole by means of sledge hammers; but they could never be so firmly fixed as to resist the expanding ice, which some time afterwards pushed out the plugs with great force and velocity; a bolt or cylinder of ice immediately shooting up from the hole. When a plug was used with springs to lay hold of the inside of the shell, so that it could not possibly be pushed out, the force of the expansion split the shell. The great distance to which these iron plugs were thrown shows the amazing power of the expansion of frost; a plug of $2\frac{1}{2}$ lbs weight being thrown 415 feet from the shell."—*Letters from Canada*, by Hugh Gray, 8vo, London, 1809.

14. *Change of temperature.*—Page 31, line 21.

Not only animals and vegetables, but mineral bodies also, are affected by the changes of atmospheric temperature. Metals are well known to expand or contract by such alteration ; and in the 75th volume of the *Philosophical Transactions*, General Roy has shown that the expansion of the steel pendulum of a clock is such, that every four degrees of the thermometer will cause a variation of a second per day in the going of the clock. See an Essay on this subject in Nicholson's *Journal*, 4to, vol. i. p. 56. Brass wire will be absolutely altered in its nature, merely by being suspended in a *damp* atmosphere. Madame Roland describes a very singular kind of harp which she says she saw in the garden of Mr. Haz, type-founder at Basle in Switzerland, which must have been made on this principle of expansion. "It is composed," she says, "of fourteen wires, closely disposed, fastened at one end to a pavilion, and at the other to a wall at the extremity of the garden, and at the distance of about 500 feet. The variations of the temperature of the atmosphere excite the vibrations of these wires, and make them sound in a singular manner. In settled weather, constantly fair, or constantly rainy, the instrument is silent. If any change is to happen, if any distant storm is rising, of which no appearance is yet perceived,—if contrary winds are ready to contend for empire, the ærial music begins, and thus announces the revolutions of its element sometimes twenty-four hours beforehand."—Madame Roland's *Tour through Switzerland*.

15. *Impaired by boiling.*—Page 97, note 1, line 3.

In making decoctions of dye-woods, it is often important not to exceed a certain temperature ; but this is very difficult to be attained by boiling them over a naked fire. Recourse has therefore been had to the expedient of conducting these processes by the agency of steam. It has however been found, that where vessels are heated by the steam being thrown *within-side* them, the contents cannot be made hotter than within one or two degrees of the boiling temperature ; whereas if one vessel be fitted *within-side* another vessel, and the cavity between them be regularly supplied with vapour from a high-pressure steam-engine, and accurately closed so as to preserve every portion of the steam from escaping, the water or other liquid in the inner vessel will be readily brought to a full boiling heat, and it will acquire this temperature even much sooner than a similar vessel with its contents would, if placed over an open fire, or fixed in a common furnace of brick-work as boilers usually are.

Being some time ago at a large manufactory in the North of England, where the proprietors are as obliging and communicative as they are scientific and intelligent, I took the opportunity of making some experiments as to the time that vessels of this latter construction require, in order to be fully heated by steam. These gentlemen have a row of five small coppers, purposely for making colours, and they are as completely fitted up as could well be devised. An iron pan that has a broad flange is first set in the brick-work, with a furnace door as usual. Within this iron pan a smaller one of copper is fixed, having a small flange by which

it hangs so as to preserve it about an inch from the outer one in every part. A strong hoop of wrought iron is then laid upon the flanges of both, with a layer of cloth between, and riveted on, so as to make the whole air-tight. A steam-pipe communicates with the outside of each of these copper boilers; therefore, by merely turning a small cock, the steam rushes into the space between the two vessels, and heats in a few minutes the copper pan with its contents.

The vessel I made choice of for my experiments measures 18 inches deep, 20 inches in diameter at the top, and is of a capacity to hold 20 gallons. This was filled with cold water taken immediately from the river, the temperature of which was at 52° of Fahrenheit. When the steam had been turned on six minutes, the 20 gallons of water were raised from 52° to 190° , in two minutes more to 200° , in other two minutes to 208° , and in one minnte more, making in the whole eleven minutes, to 212° .

Being desirous, however, of taking the temperature at shorter intervals, I fixed upon another copper of the same dimensions, that was fitted up in the same way; and as this, like the former, was quite cold, not having been used for some time, it was very proper for my purpose.

When 20 gallons of water at 52° were measured into it, the steam was turned on, and the time accurately noted by a stop-watch.

The water rose,

in 1 minute, to	82°	in 6 minutes, to	176°	in 10 minutes, to	$206\frac{1}{2}^{\circ}$
2 minutes, to	108	$6\frac{1}{2}$	182	$10\frac{1}{2}$	208
3	128	7	188	11	209
$3\frac{1}{2}$	137	$7\frac{1}{2}$	193	$11\frac{1}{2}$	210
4	146	8	198	12	$210\frac{1}{2}$
$4\frac{1}{2}$	154	$8\frac{1}{2}$	201	$12\frac{1}{2}$	211
5	162	9	203	13	212
$5\frac{1}{2}$	169	$9\frac{1}{2}$	205		

This vessel was in the form of an inverted bee-hive, with the bottom brought to a small point; that in preparing colours any sediment might be the more readily collected together and removed. The outer vessel is of cast iron, the inner as before said of copper, with a space of about an inch between them. A pipe is adapted to the bottom of the outer vessel, with a stop-cock for occasionally drawing off the water that proceeds from the condensed steam; for, if this be not done frequently, it retards the heating of the inner vessel. To the want of proper attention to this I attribute the difference in the time which was required in these experiments to bring the water to a boiling heat; for, though both vessels were of the same capacity, the one boiled in eleven, whilst the other required thirteen minutes; though the treatment in every other respect was the same. The outer vessels are lapped over with straw, and so are the conducting pipes; and both are then neatly plastered with mortar, to prevent any unnecessary escape of caloric. The main pipes are of cast iron, screwed together by double flanges; the smaller pipes are of lead—although copper is better for these, lead being very liable to bend and become out of order.

In preparing some of the colours for calico-printing, the decoctions are boiled with flour-paste for a very considerable time, until the whole be-

comes a thick mass. In this process, if the heat be given as usual by a coal fire underneath the vessel, it is extremely difficult, if not impossible, to prevent the matter from burning in some measure by its adhesion to the sides or the bottom of the pan, and this never fails to affect the beauty of the colour, independently of the loss that is sustained by that portion which actually becomes carbonized by the accident. Now, wherever steam is employed in preparing colours, this effect cannot happen; and though the colour may perhaps be injured by its being treated at too high a temperature, it can never suffer by burning to the bottom of the vessel; for the heat is equal in every part, and can never be so great as to produce this effect.

A very complete apparatus for the preparation of pharmaceutical articles by means of steam, has been erected by the Company of Apothecaries, at Apothecaries' Hall, London, and found very useful and highly economical.

Indeed, for most of those processes that would require no higher temperature than that of about 208° any common culinary utensil, either of earthenware or metal, might be employed, and this would fully answer for most purposes.

16. *Hot-pressed*.—Page 97, line 21.

A considerable expense and some uncertainty attend the operation of hot-pressing that species of stuff goods called bombazets, besides a waste of heat that is truly surprising. It has occurred to me that an important improvement might be made in the process, and therefore I think it right to describe the operation as it is now conducted, and then suggest the alteration I would recommend. In the manufactory which I had the opportunity of inspecting, they have six very powerful presses, each of which will contain at least thirty pieces of goods when piled singly one above the other, with a cast-iron plate one inch thick between each piece. As the pressure would not produce the desired effect without heat, they obtain this by heating the iron plates preparatory to the operation. For this purpose they have two very large ovens, each of which has an iron bottom several inches thick; and when these ovens are to be used, fires are lighted underneath them, and kept burning until the bottom becomes of an intense red heat. These ovens are for the express purpose of heating the iron plates; but as the workmen have no means of ascertaining with accuracy when they are of a proper heat, they usually keep them in the oven until they are nearly red-hot; they are then drawn out, and the heat lowered, by placing a cold plate of iron between each of them. In this state they remain for an hour or two, exposed to the cold atmosphere, till the superadded plates become nearly of the same temperature. But notwithstanding this precaution, they are often found too hot to put between the goods at a time when the presses are emptied to receive them; they are therefore sprinkled with water to cool them to that particular point when they may be used with safety. The iron plates which I saw employed, were twenty-one inches long, ten inches wide, and one inch thick. The pieces of bombazets are folded with a sheet of that kind of glazed pasteboard known by the name of press paper, placed between each fold; and when the whole piece is thus folded up, it is of a proper

width and length to be exactly covered by three of these hot iron plates laid side by side of each other. When a piece thus folded is placed in the press, and covered with three of the iron plates, another piece is laid upon it, which is covered with plates in like manner; and this alternate arrangement of the manufactured goods and the iron plates is continued until the press becomes full.

It appears to me that it would be easier and cheaper to have steam chests adapted to each of the four sides of these presses, and also between the goods occasionally, if the steam at the sides only should be found to be insufficient.

NOTES TO ESSAY III.

ON SPECIFIC GRAVITY.

17. *Purity of the metals.*—Page 105, line 7.

In the year 1670, Mr. Smethwick, a Fellow of the Royal Society, published a table of the weights of a cubic inch of several of the metals, which was printed in one of the early volumes of the *Transactions of the Royal Society*. It was afterwards published in a small octavo volume, entitled "*The Secrets of the Goldsmith's Art*," London 1676. Dr. Musgrave also published a table of the specific gravity of various bodies, from experiments made hydrostatically. See *Philosophical Transactions*, No. 169. Mr. John Caswall, in the year 1693, likewise published a table of specific gravities, under the signature of J. C. This was printed in the *Phil. Trans.* No. 199.

NOTES TO ESSAY IV.

ON BARYTES.

18. *Sulphate of barytes.*—Page 124, line 16.

In addition to the various kinds of native sulphate of barytes already mentioned, it may be proper to notice the foliated baro-selenite of Kirwan, or what Jameson calls the straight lamellar heavy spar; because it has been applied to some peculiar uses to which the other species are not applicable. It occurs massive as well as crystallized in different forms, and of a great variety of colours. It is found in veins in the different primitive rocks; and beautiful crystallized varieties are brought from the lead mines of Cumberland, Durham and Westmoreland; it is known also on the continent of Europe and in America. It is sometimes used as a dressing for land; and when burnt and finely ground, it has been used instead of bone-ash for making cupels. The white varieties of the foliated baro-selenite have been employed as white colours in painting, and for pastil-pencils; and it has sometimes been used as a flux for ores of particular kinds.

"The granular baro-selenite is one of the rarer species of this genus of ponderous earth. That of *Peggau* in the duchy of Stiria occurs of a beautiful milk-white colour, is massive, resplendent, finely grained, semi-indurated, and brittle. It bears a very strong resemblance to the white

fine-grained Carara marble, to such a degree, that, by its mere appearance, it might easily be mistaken for it, were it not for its greater specific gravity, which is 4.380, and by which it is readily distinguished."—*Klaproth's Analyt. Essays*, vol. i. p. 375. On analysis it is found to consist of barytes 60, sulphuric acid 30, and silex 10.

19. *Barytes and strontites*.—Page 138, line 1.

Having in the Essay on Barytes adverted only to the most striking marks of difference between that earth and strontites, I am desirous in this place of noticing the other differences which have been observed respecting them.

Muriate of strontites is much more soluble in hot water than in cold ; muriate of barytes, on the contrary, is nearly as soluble in cold water as in hot, and crystallizes by evaporation. An ounce of pure water at 70° dissolves 9 drachms and 50 grains of the former salt ; whereas the same quantity of water at the same temperature, only dissolves 3 drachms and 35 grains of the latter. The former produces 25° of cold by its solution ; the latter not more than 5°. Carbonate of barytes is highly poisonous ; carbonate of strontites may be taken internally without danger. The usual colour of carbonate of barytes is a yellowish or grayish white ; the colour of carbonate of strontites is usually light green, though it is sometimes found colourless and transparent. When both these native salts are submitted to heat, it is found that the carbonic acid is less strongly retained in the carbonate of strontites than in that of barytes.—See Pelletier's *Observations on Strontites* in the *Annales de Chimie*, tom. xxi. p. 113 ; or Nicholson's 4to *Journal*, vol. i. p. 518, &c.

NOTES TO ESSAY VI.

ON CARBON.

20. *The diamond*.—Page 149, line 3.

In the year 1745, Mr. John Ellicott, F.R.S. ascertained the specific gravity of 14 large diamonds, with a pair of assay scales, which very sensibly turned with the 200dth part of a grain, and the mean of his experiments gave a specific gravity of 3.517.—See the *Philosophical Transactions*, No. 476. For an explanation of the principle on which the diamond carat weight was originally constructed, see Dr. Davies's *Tables of Specific Gravities*, 4to, London 1750, p. 19.

The largest known diamond is that, mentioned by Tavernier, in the possession of the Great Mogul. Its size is about that of half a hen's egg ; it is cut in the rose form, and when rough, weighed 900 carats. It was found in Golconda about the year 1550. The Pitt diamond belonging to the Crown jewels of France is the most perfect and beautiful diamond yet found ; it weighs 136 carats, and was purchased for 100,000*l.*, and is now valued at double that sum.

The ancients were unacquainted with the art of cutting the diamond. The four large diamonds that ornamented the clasp of Charlemagne's mantle, which is still preserved in Paris, are uncut octohedral crystals.

The primitive form of the diamond is the regular octohedron, each triangular facet of which is sometimes replaced by six secondary triangles, bounded by curved lines, so that the crystal becomes spheroidal, and presents 48 facets. Diamonds with 12 and 24 facets are not uncommon.—*Brande*, vol. i. p. 415. The transparent snow-white diamond is considered to be the most valuable; the green and yellow varieties are also much esteemed, and the least valuable are the gray and brownish varieties. Black diamonds are the most rare, and consequently are much prized by collectors.—*Jameson's Mineralogy*, vol. i. p. 1—14.

21. *Gunpowder*.—Page 162, line 26.

Before the introduction of gunpowder, a highly inflammable compound called the *Greek fire* was in use; and this, having the property of burning under water, could not easily be extinguished; consequently it did surprising execution. In the 12th century the Emperors of Constantinople used to send quantities of this dreadful combustible to princes in friendship with them, as the most valuable present they could give them, and the greatest mark of their favour. This was considered to be so important an article of offence, that the use of it was continued long after the introduction of gunpowder; for it appears, when an English army commanded by the Bishop of Norwich besieged Ypres in the year 1383, the garrison defended themselves so well with stones, arrows, *Greek fire*, and certain engines called *guns*, that they obliged the English to raise the siege with such precipitation, as to leave their great cannon, which were of inestimable value, behind them.—*Walsingham (Thomas), Historia Brevis ab Edwardo I. ad Henricum V. folio*, London 1574, p. 303.

Iron cannon were not made in England for a long time after they had been in use on the Continent, as the first foundry of this kind is said to have been formed in 1535 by an individual of the name of Owen; and in the year 1547 one Pierre Baudet, a foreigner, cast-iron cannon in the neighbourhood of London. The first reference in Rymer to the use of iron cannon balls is in 1530.—*Rymer's Fœdera*, vol. xv. p. 18.

22. *Nitre*.—Page 163, line 2.

"The History of the making of Saltpetre, by Mr. Henshaw," together with directions how to proceed in refining it, was published in *Sprat's History of the Royal Society*, 4to, p. 260—276. An elaborate memoir by Chaptal, on the formation of saltpetre and the establishment of artificial nitre beds, will be found in the *Annales de Chimie*, tome xx. p. 308—369. An account of the French method of procuring saltpetre since the Revolution, may be seen in the *Tradesman's Magazine*, vol. ii. p. 533.

In the sixth volume of the *Annales de Chimie*, p. 365, it is announced that M. Lowitz has published in *Crell's Chemical Annals for the year 1792*, a new Essay on the purification of saltpetre by powdered charcoal.

23. *Ink of the ancients*.—Page 172, line 42.

A writer of the 16th century recommends "the preparation of an

aqueous decoction of galls, and that when ink groweth thick, to thin it with this rather than with beer, vinegar, or any other fluid."—Platt's *Jewel House of Nature and Art*, p. 43. There is great room for improvement both in the manufacture of writing- and printing-ink. Dr. Lewis has written on both these kinds of ink with great knowledge of his subject.—See the *Commercium Philosophico-Technicum*, p. 371—401. It seems extraordinary, but for a long time much finer ink for the use of the printer was manufactured at Madrid than in any other part of Europe. "The art of printing was carried into Spain by the Germans, who travelled from city to city with their types and presses. Ibarra, who is well known by his superb edition of *Don Quixote* in four volumes 4to, employs an ink so superior to all others, that our printers have often endeavoured to discover the secret of its composition, the works which he published having rivalled those of the renowned Bodoni of Florence. Punches, matrices, types and paper, are all fabricated in Spain, not only at Madrid, but also in several of the provinces; where the Spanish presses have produced editions of books not less fine than that of the Sallust printed by Don Gabriel the younger."—See *The Campaigns of the French Armies in Spain and Portugal in the Years 1808 and 1809, with a statistical Description of those Kingdoms*, 8vo, Paris 1809. Excellent directions by Desormeaux for making good writing-ink may be seen in the *Philosophical Magazine*, vol. v. p. 158. Some important remarks by Ribaucourt on the same subject will be found in the *Repertory of Arts*, vol. ix. p. 205.

NOTES TO ESSAY VII.

ON SULPHURIC ACID.

24. *From sulphate of iron.*—Page 213, line 2.

I have stated that the sulphuric acid formerly made in this country was procured from sulphate of iron; but I forgot to notice that the oil of vitriol which is prepared in this way, gives out acid fumes when it is exposed to a damp atmosphere. It also congeals sometimes and crystallizes as it were, and hence such acid acquired the name of *glacial* oil of vitriol. From these circumstances it is evident that it must differ in a considerable degree from the sulphuric acid as it is now usually prepared. Dr. Thomson considers it to be of greater strength than the common sulphuric acid, that it is pure anhydrous acid; but Professor Brande thinks it more probable that it consists of sulphuric acid, combined with a portion of sulphurous acid. The subject deserves further examination, especially as so much sulphuric acid is now made by a patent process from martial pyrites or sulphuret of iron.

25. *Martial pyrites.*—Page 213, line 16.

In the year 1818 Thomas Hills and Uriah Haddock, of Bromley in the county of Middlesex, obtained a patent for making sulphuric acid from martial pyrites, or other native sulphurets, without the use of nitre. The process consists in submitting these native productions to a red heat in

a reverberatory furnace, and conducting the fumes arising from the combustion into a leaden chamber formed as usual, and with the floor covered with water. As these patentees have made offers to various other manufacturers to sell them the right to make use of this process, they have stated that the sulphur passes in the act of combustion at once into the state of sulphuric acid, without the aid of nitre.

Having expressly written on the manufacture of sulphuric acid, I have thought it right to apprise my readers of the existence of this patent, and to give it as my decided opinion, that what they profess to do is utterly impossible. I know Messrs. Hills have a large establishment for the production of sulphuric acid from iron pyrites, and that the sulphuric acid they make is of very good quality; but I believe it is not made without a considerable quantity of nitre, though they have thought fit entirely to omit the mention of that article in their specification. They speak of throwing steam and some *imponderable* substance into the leaden chamber occasionally; but what this imponderable substance can be, it is impossible to imagine, as it is well known that nothing except nitre has yet been discovered, that can with economy be employed to convert sulphurous to sulphuric acid.

NOTES TO ESSAY VIII.

ON CITRIC ACID.

26. *Separating the mucilage.*—Page 248, line 25.

The mucilage contained in lemon or lime juice has always been considered to be the main obstacle to the crystallization of the citric acid contained in the expressed juice of these fruits. Having lately, however, seen a Report made to His Majesty's Victualling Board by an eminent chemist, stating that the concrete acid may be obtained from lemon juice by the simple mode of evaporation only,—an assertion contradicting every thing which I had hitherto observed respecting the concentration of this article,—I wrote to a friend who has had more experience than myself in the preparation of concrete citric acid, and received the following reply to my letter: "An attempt to procure the crystallized acid by the mere evaporation of the lemon juice was," says he, "among the earliest experiments I made on this subject. The simple evaporation of the juice, I find, produces merely a thick treacley kind of substance, and by pushing the concentration further, it may be brought into the state of honey. I still prosecuted the inquiry, in the vain hope of being able to procure a concrete acid by the agency of lime. The mass procured by evaporation I diluted with cold water, making my solution about four or five times the strength of good lemon juice. To one pint of this solution I added one ounce of alcohol; and having reduced this one-fourth by evaporation, it was set aside to cool. On the following day I found a considerable precipitate, which I separated by filtration, and I again evaporated the mother liquor. This treatment I continued from time to time till the whole was reduced to a thick substance similar to molasses as before, but there was no sign of any tendency to crystallization. I

repeated this experiment with different proportions of alcohol, but the result was always the same ; and I closed the series of experiments with a conviction of the impossibility of procuring concrete citric acid by the mere evaporation of lemon juice."—For further information on the crystallization of citric acid, see the xvth volume of *The Repertory of Arts and Manufactures* ; also volume xii. of the same work, p. 347.

NOTES TO ESSAY IX.

ON THE FIXED ALKALIES.

27. *Rendered caustic.*—Page 277, line 27.

As it is important to those who use large quantities of the fixed alkalies to know when a proper quantity of lime has been used to render them caustic—the following directions will probably be acceptable to many individuals. When the solution of caustic alkali is prepared, take a little of the clear liquor in a wine-glass, and breathe into it through a small glass tube, or otherwise add a few drops of a clear solution of sub-carbonate of potash ; for if there be a redundancy of lime, the dissolved earth will absorb carbonic acid from the carbonate of potash or from the human breath, and this will render the liquor turbid. If this treatment should not occasion the liquor to become turbid, it should then be treated with a little lime-water ; and if this occasions a turbidness, it shows that the liquor contains carbonated alkali, and consequently has not had a sufficient quantity of lime ; whereas, if the lime be in due proportion, the lixivium will suffer no change from the addition of the above tests, nor will it effervesce with acids.

Directions for the preparation of pure potash and soda by means of alcohol are given in Dr. Henry's *Elements of Chemistry*, vol. i. Whenever it is necessary to open a bottle of pure alkali, it should be done in a dry air or near a fire, and then the stopper immediately returned, and carefully secured by wax as at first.

28. *Kelp.*—Page 289, line 30.

Jameson states, that barilla contains from $8\frac{1}{2}$ to 23 per cent. of pure alkali divested of water and carbonic acid, and that kelp contains from 2 to 5 per cent. From an analysis which I myself made of three parcels of barilla in the year 1801, one of which was from Alicant, another from Carthagena, and the third from Teneriffe, all of which were at that time esteemed to be the best samples in the London market ; I found that 112lbs of the first contained 19lbs 2 oz. of pure dry caustic alkali ; 112lbs of the second contained $22\frac{1}{4}$ lbs of alkali ; and the Teneriffe $22\frac{3}{4}$ lbs, which was esteemed much better than is usually brought from that island.

Four parcels of barilla which I examined with great care on the 4th of June 1810, were found to be composed as under :—The first parcel consisted of 19 parts pure soda, 22 of neutral salts and carbonic acid, and 59 of insoluble matter. The second parcel gave 18 per cent. of

pure alkali, 21 of neutral salts, &c., and 61 of insoluble matter. Another contained $10\frac{3}{4}$ pure alkali, 24 neutral salts, &c., 65 of insoluble matter, and $\frac{1}{4}$ loss. The fourth parcel consisted of 11 parts of pure alkali, 20 neutral salts, &c., and 69 of insoluble matter.

Two other samples were analysed on the 1st of February 1813 : one of which contained $30\frac{1}{4}$ per cent. of pure dry soda, $10\frac{3}{4}$ neutral salts, 9 carbonic acid, and 50 insoluble matter. This was the best sample of barilla that I recollect ever to have come under my examination. Kelp is of very various quality ; I have seen some which contained 8 per cent. and others which would not yield one per cent. of pure soda. The particulars of the analysis of several parcels of kelp and barilla which I made for the Highland Society of Scotland in the year 1816, will be found in the 5th vol. of the *Transactions* of that Society, p. 65, &c.

29. *Kelp ovens*.—Page 290, line 12.

The ovens in which kelp is made are generally of the rudest kind, being nothing more than excavations within the ground, lined with rough unhewn stones. I would earnestly recommend it to the proprietors of our kelp shores to erect one or more reverberatory furnaces similar to that described in the plate which accompanies the *Essay on the Fixed Alkalies* ; for by means of such furnaces a greater heat would be produced, and the matter might be stirred with greater convenience ; and hence there would be a more effectual decomposition of the muriate of soda by means of the vegetable alkali which these plants always furnish in abundance. By such management I apprehend much of the Irish and Scotch kelp might be rendered of double its present value. See the plate and the descriptions given of it at the beginning of this volume.

30. *Supplies of salt inexhaustible*.—Page 303, line 14.

“ We read of a salt mine in Poland, one mile from Cracow, which is 200 fathoms below the surface, where there were 1000 men constantly employed. In order to descend into this stupendous work, it was customary for the person descending to fasten himself by a cord to the main rope, and then to take another man on his lap. The large rope being then lowered a little, a third person made a seat for himself with a rope fastened to the main rope, taking another on his lap ; and being also let down a little way, he gave an opportunity for another pair to fasten themselves in the same way : in which manner thirty, forty, or more people were let down at once ; of whom the first having touched the ground at the bottom, steps out and goes aside, the rest following him in regular order and doing the like. Thus they descended to the depth of 100 fathoms ; and after passing through several passages they came to certain ladders by which they descended 100 fathoms deeper.”—*Phil. Trans.* for 1670, p. 1099.

The salt mine above mentioned is at the town of Wielitska, a German mile from Cracow : it is the largest in Europe, and has been constantly worked for more than 600 years : it is eleven hundred feet in width, and 6700 feet in length. The subterranean passages or galleries are very spacious, and in many of them altars or chapels are hewn out of the salt rock. In these chapels, crucifixes or the images of saints are set up ;

and a light is kept continually burning before them. The places where the salt is hewn out of the mine, are called chambers ; and some of these are so spacious that a large church might be inclosed in one of them. When candles are brought into these places, the numerous rays of light reflected by the crystals of salt emit a surprising lustre. About 600,000 quintals of salt are annually dug out of these mines. That part of the mine which has been most excavated, and which appears like a vast plain, is interspersed with clusters of huts belonging to the miners and their families, many hundreds of whom are born and finish their lives in this subterranean inclosure.

While on the subject of salt, I embrace the opportunity of mentioning a new purpose to which salt has been applied, and which certainly deserves to be registered for the benefit of the public. Some merchants of Liverpool, who in the year 1815 had prepared several hundred carboys of oil of vitriol to be exported to America, had them stowed on board two ships, and filled up all the vacant spaces between the baskets with common salt to prevent the bottles from being broken by the motion of the vessels. Proposals for the insurance of these precious cargoes were sent to Lloyd's, and the circumstance of the stowage in salt was mentioned to induce the underwriters to insure at a lower premium. Some gentleman, however, who knew the effect which would be produced by the affusion of oil of vitriol upon salt, saw the proposals at Lloyd's, and stated that if a single bottle should by any accident become broken on the passage, every individual on board would inevitably be suffocated. It was, however, too late to take any precautionary measures, for the vessels had then both actually sailed. The names of the ships which were then crossing the Atlantic in such a perilous situation were the *Lewis* and the *Margaret*, I believe both of Liverpool. Should either of these vessels have sprung a leak, so as to dissolve much of the salt, the stowage of the carboys would have been loosened, and some of the bottles would unavoidably have been broken, by the rocking of the ship.—Here we have another instance how necessary it is that all classes of society should become acquainted with the elements of chemical science.

31. *Rocks of salt.*—Page 303, line 15.

Notwithstanding these immense masses of salt found in various parts of the world, there are places where salt has never yet been discovered : this is the case in many parts of Africa. Mungo Park relates that “ the greatest of all luxuries in the interior of Africa is salt. It would,” says he, “ appear strange to an European to see a child suck a piece of rock salt as if it were sugar. This, however, I have frequently seen ; although the poorer class of inhabitants are so very rarely indulged with this precious article, that to say that a man eats salt with his provisions, is the same as saying he is a rich man. I have suffered great inconvenience myself from the scarcity of this article. The long use of vegetable food creates so painful a longing for salt, that no words can sufficiently describe it.”—Park's *Travels into the Interior of Africa*, quarto, 1799.

NOTES TO ESSAY X.

ON EARTHENWARE AND PORCELAIN.

32. *Roman bricks*.—Page 304, line 18.

Brick-making was esteemed an art of great consequence by the ancient Romans ; in proof of which the following evidence presents itself. *ABDALA*, the slave who waited on the person of the empress Livia the wife of Augustus, was set over all the slaves that made bricks ; and in the year 1738, on exploring the remains of the ancient city of Heraclea, it was observed that one of the bricks bore the name of *Abdala* and also that of his mistress the empress. This appears the more extraordinary, because soon after the time of Augustus a law was enacted, ordaining that no architect should be allowed to affix his name upon any part of a building which he had erected, even though it should have been built at his own expense.—See *A Description of the first Discoveries of the ancient City of Heraclea*, translated by Wickes Skurray, 8vo, 1750, p. 58. —Pliny says that “Euryalus and Hyperbius, two brothers, at Athens, caused the first brick- and tile-kiln to be erected, yea and houses thereof to be made ; whereas before that time men dwelled in holes and caves within ground. Gellius is of opinion that Doxius the son of Cœlus devised the first houses that were made of earth or clay.”—Holland’s *Pliny*, vol. i. book vii. p. 188.

33. *Water-pipes*.—Page 305, line 38.

Some idea of the state of the potter’s art among the ancient Romans may be conceived from the following passage in Pliny. “How beneficial,” says he, “is the earth unto us in yielding us conduit-pipes for conveying water, tiles flat yet hooked and made with crotchets at one end to hang upon the sides of the roof, chamfered to lye in gutters to shoot off water, curbed for crests to clasp the ridge on both sides, to say nothing of the vessels that be turned with the wheel and wrought round ; yea and great tuns and pipes of earth devised to contain wine and water also ! In regard of which Numa ordained at Rome a seventh confraternity of potters.”—Pliny’s *Natural History*, book xxxv. chap. 12. p. 551.

34. *Roman earthenware*.—Page 306, line 14.

A large vessel of Roman earthenware was found during the winter of 1813 at Ambleside in the county of Westmoreland, where it is supposed an old Roman city originally stood. But the most interesting detail that I have met with of their earthen vessels is in the account of the discovery of the ancient city of Heraclea, as described by Marquis Don Marcello di Vinuti, in a work already quoted. “Through a door of white marble,” says the marquis, “we came into a room 14 yards long and eight broad, which led into another room of the same length, but almost square. Round the inside of both these rooms there ran along close to the wall,

about half a yard high, a kind of bench covered with a marble pavement, which seemed at first sight to have been used for a seat ; but on coming to examine it nearer, I perceived on the top some round stones or stopples of marble ; which, being removed, I found were the covers of some great earthen jars, set in with mortar, the necks of which were inclosed just within the bench. These vessels were of a roundish form, and would hold ten barrels Tuscan measure each. On one of these vessels was this inscription: OPUS. DOLIARE. VINARIUM. The names which were on the handles and necks of these vessels were the names of the makers. Those wrote with ink were the names of the owners of the liquor contained within ; and by reason of the multiplicity of names, it is imagined to have been a cellar for the use of the soldiers who were stationed there to guard the walls ; and that whosoever name was wrote on the vessel, to him belonged the wine contained therein, whether he bought it, or it was his allowance.”—Skurray’s translation of the *Description of the Discoveries at Heraclea*, page 110.

It is generally believed that the ancient Egyptians had also made great progress in the knowledge of the manufacture of Earthenware. Mons. Belzoni says, “The art of varnishing and baking the varnish on clay were in such perfection that I doubt if it could be imitated at present ;” and this remark was the result of his own observations.—Belzoni’s *Researches in Egypt*, quarto, p. 173.

35. *Lapis lazuli*.—Page 307, line 11.

“This mineral,” says Guyton, “may be urged to a red heat, and even lose 0.2 of its weight, without any visible alteration in its colour ; but with a stronger heat, such as that of the furnace of an enameller, its colour changes to gray.”—Guyton, *Annales de Chimie*, tom. xxxiv. p. 58. Mr. Delaval supposes that the colour produced from lapis lazuli was applied to the painting of porcelain, after the ware had undergone the heat of the furnace, and before the introduction of cobalt.—Delaval’s *Inquiry into the Cause of the Changes of Colours in opaque and coloured Bodies*, 4to, London 1777, p. 58.

36. *Bernard de Palissy*.—Page 311, line 25.

Palissy is said by Fontenelle to have gone as far in the character of a philosopher as genius without learning could carry him. This eminent man, when in his pleasant moments, used to say, in reference to his trade as a potter, that “he had no property whatever, except heaven and earth.”—*Nouveau Dict. Hist.* art. PALISSY, viii. p. 261. No one can have read the History of the Life of Palissy without wishing to know every thing respecting him. For an account of the books published by him, and of the nature of his writings, the reader may consult Platt’s *Jewel House of Art and Nature*, part ii. quarto, London 1594.

37. *Vases*.—Page 315, line 12.

A beautiful collection of Engravings of the ancient vases in the British Museum and elsewhere, has been published by Mr. Moses, with disser-

tations on the vases of antiquity. This superb work is entitled *A Collection of Vases, Altars, Pateræ, Tripods, Candelabra, Sarcophagi, &c. from various Museums and Collections, engraved on 170 Plates*, by Henry Moses, with Historical Essays, quarto, 1814. Another splendid work of this kind is Sir William Hamilton's *Collection of Engravings from ancient Vases, mostly of pure Greek Workmanship*: three imperial folio volumes, Naples 1791—1795.

38. *An unwholesome glaze.*—Page 334, line 12.

In addition to what I have said respecting the danger of using a glaze of lead on any of the articles made in earthenware which are to be employed in preparing condiments for our food, I must add another caution, which is, never to prepare pickles or any thing in which vinegar is used, in jars of cream-coloured ware; for this ware is always glazed with lead, and the lead being soluble in vinegar would impart a poisonous quality to the preparations contained in it. When will the community entertain proper notions respecting the deleterious properties of this insidious poison? In Lancashire I have observed it is a common practice to have brewing-coppers constructed with the bottom of copper, and the whole sides of lead. In the same county the dairies are furnished with milk-pans made of lead; and when I expostulated with some individuals on the danger of this practice, I was told that *leaden* milk-pans throw up the cream much better than vessels of any other kind. In some parts of the north of England it is customary for the innkeepers to prepare mint-salad by bruising and grinding the vegetable in a large wooden bowl with a *ball of lead* of twelve or fourteen pounds weight. In this operation the mint is cut, and portions of the lead are ground off at every revolution of the ponderous instrument.

39. *Printing press.*—Page 338, line 4.

If we consider the many beautiful coins and medals which the ancients produced when the Roman empire was in all its glory; likewise the cornelian and agate seals which they engraved on soft wax; together with the practice which was very general among that people, of having their names impressed in capital letters on the large earthen jars in which they kept their wine, we cannot avoid being surprised that they never arrived at some method of printing books. An interesting dissertation on this subject may be seen in the *Philosophical Transactions*, No. 450, p. 388. Procopius, in his *Hist. Arcana*, says, that the Emperor Justin, not being able to write his name, had a thin piece of board, through which were cut holes in form of the four first letters, which was laid on the paper, and served to direct the point of his pen. For the date of the origin of printing on paper, see the 1st Additional Note.

40. *Crucibles and retorts.*—Page 339, line 38.

The Indians of Louisiana form their culinary utensils with clay mixed with a sort of calcined mica. Of this composition they also make crucibles.

capable of enduring the strongest heat they can produce. The galena, which is found there in abundance, is fused in these crucibles, by exposing it to a strong heat, in a sort of furnace made by excavating a bank of earth, and forming a chimney through the top of the cave to produce a strong draught of air. The lead thus obtained is employed only for the purpose of sinking their fishing nets.

There are remains of many ancient potteries in the neighbourhood of Salem in the United States, on the shore of lake Erie. On the Ohio and Mississippi, they are found of a more recent era. In the ancient sepulchral barrows, vessels are found equal to any now manufactured in any part of the world. Two covers of vessels were found in Ross county highly polished and made of a calcareous breccia; fragments of these were examined by my friend Professor Silliman, of Yale College, Connecticut; and were found to be equal in texture and execution to vessels of a similar material now manufactured in Italy.—See *Archæologia Americana*, vol. i. p. 219—227.

NOTES TO ESSAY XI.

ON GLASS.

41. *Coloured glass*.—Page 350, line 19.

Strabo, who visited Alexandria in the first century, was told by the workmen there, that their country afforded an ingredient without which coloured glass could not be made.—*Strabo*, lib. xvi. p. 758. There is in the British Museum a mummy of great antiquity which is covered with beads of coloured glass. According to Seneca, coloured glass has been made in Europe for more than 2000 years. “Democritus,” says he, “brought into Europe the method of making coloured glasses, and thereby counterfeiting gems.”—Seneca’s *Epistles*, 90.

42. *Virgil’s glass mirror*.—Page 358, line 10.

This must have been an uncommon utensil at the time in which Virgil lived, for in that age and long afterwards mirrors were usually metallic. Job describes the heavens as a molten looking-glass; and by the order of Moses the brazen laver of the priests was manufactured with the mirrors of the women assembling at the tabernacle.—*Exodus*, chap. xxxviii. verse 8. Valerian made the Emperor Probus a present of a silver cup, the inside of which was cut into mirrors. Pliny and Seneca relate that every young woman in their times expected to have a silver mirror. *Pliny*, book xxxiv. chap. 17. Indeed the mirror-makers of Rome, who were generally silversmiths, were so numerous that they were formed into a Company.

43. *Manganese*.—Page 358, line 15.

For a further explanation of the action of the black oxide of manganese in purifying flint glass, consult the article “Glass” in Aikin’s *Chemical*

Dictionary, or *Loysel Sur l'Art de la Verrerie*, page 168, § 101. When too much of this oxide has been employed, so as to occasion a purple colour in the glass, it is usual for the workmen to thrust a piece of wood into the mass of melted metal, which quickly abstracts the colour. This oxide imparts its colour to glass only when it is in a high state of oxidization: the wood therefore becoming carbonized abstracts a part of the oxygen, and the colour of the glass disappears.

44. *Technical terms*.—Page 358, line 42.

The technical terms in the glass trade are most of them taken from the Italian or French, but some are derived from the German language. *Pontilla* is from the Italian, meaning any thing drawn to a point or derived from a point. *Cavelletta*, the head or crown of the reverberatory furnace, is also from the Italian. *Schrower* is the room at the end of the *lier*, where the goods are received when annealed; this is from the German. *Fraiche* is the iron pan in which the glass is placed to be cooled or annealed. *Parcellas* is a kind of pincers with a spring back, which is in constant use in those houses where flint glass is made. These terms are all still employed by the glass-makers of Great Britain.

NOTES TO ESSAY XII.

ON BLEACHING.

45. *Wool of animals*.—Page 388, line 24.

Although the woollen manufacture appears to have been lost during the reigns of Henry III., Edward I., and some of their successors, there is abundant evidence that the ancient Britons were very famous for the manufacture of woollen cloth. Pliny says that “the ancient Britons made a kind of cloth or felt which was so strong and firm, when vinegar was used in making it, that it resisted the blow of a sword, and was even some defence against fire. In after times, these arts were much improved amongst us by the Romans, who formed colleges and corporations, with various privileges, for instructing the people, and improving the manufacture of all articles made of woollen. One of these imperial manufactories, according to Camden, was established on the spot where the city of Winchester now stands. These efforts were so successful, that some hundreds of years afterwards we find that the fleece, by the Anglo-Saxon laws, was valued at two-fifths of the price of the whole sheep. In after times, King Edward III. took so much pains to improve this important manufacture, that during his reign it became completely established. This appears evident from a curious paper published by Mr. Rymer, containing a grant from Richard II. in the year 1382, to Cosmo Gentilis, to export several pieces of cloth of various colours, without paying any duty; the first article of which consists of six pieces of tapestry of a green ground, powdered with roses, which the King sent

as a present to the Pope.—Pliny's *Natural History*, book viii. chap. 48. *Cod. Theod.* tom. iii. p. 524. Camden's *Britannia*, vol. i. p. 139. Wilkins's *Leges Anglo-Saxonice*, &c. p. 23. Rymer's *Fœdera*, vol. vii. p. 356.

NOTES TO ESSAY XIII.

ON WATER.

46. *Logwood*.—Page 422, line 43.

The art of dyeing must surely have been ill understood in the 16th century, for the Government of Queen Elizabeth to have procured a statute to be enacted entirely forbidding the use of logwood. It is entitled "An Act for the abolishing of certeine deceitful Stuffle used in dyeing of Clothes," &c. The preamble states, that "whereas there hath been brought from beyond the seas a certaine kinde of stuffe called logwood, alias blockwood, wherewith divers dyers," &c.; and "whereas the clothes therewith dyed, are not only solde and uttered to the great deceyte of the Queenes loving subjects, but beyond the seas to the great discredit and sclaunder of the dyers of this realme," &c.; "for reformation whereof, be it enacted by the Queene our Soveraygne Ladie, that all such logwood, in whose handes soever founde, shall be openly burned by authoritie of the Maior," &c. This prohibition was renewed in the 39th year of the same reign, subjecting the person so offending to imprisonment, and on conviction thereof to stand on the pillory in the market town where the offence was committed.—See *23d of Elizabeth*, cap. ix., also *39th of the Queen*, cap. xi. Eighty years elapsed before the real virtues of this useful substance were acknowledged. It has, however, been discovered that this wood is one of the most valuable articles the dyer possesses, especially for dyeing blacks. A black may be procured by the combination of several vegetable substances with the peroxide of iron: but I have reason to believe that neither galls, madder, nor any other vegetable, will produce a fine black on cotton if logwood be entirely omitted. Hence, all the most approved receipts for writing-ink, include logwood as a principal ingredient.

47. *The fullers in ancient Rome*.—Page 431, line 16.

The inhabitants of Rome, except the lower orders of people, generally wore white woollen garments, but especially at public festivals.—Ovid, *Fasti* i. 79. This made fullers as necessary as laundresses. They were for the most part slaves, but sometimes free; for an inscription in the collection of Fabrettus, c. 4. page 333, mentions the *Collegium Fullonum*, the *Fullers' Company*, at Rome. The place where the fullers worked was generally in the fields, on account of the offensive nature of their business.—Hence Plautus, *Asin.* V. II. 57.

It appears, from the testimony of ancient writers, that the fullers first threw the clothes into water, where they trod them with their feet. Hence, as Horapollo, *Hieroglyphics*, i. 65, has observed, the Egyptians

expressed a fuller by the representation of two human feet in water. This washing by treading with the feet, the Romans called *Consilium*, à *Consiliendo*. In order to provide themselves with urine, the fullers placed earthen pitchers at the corners of the streets.—See Martial xii. 58.

The clothes, having been thus repeatedly trodden upon in water and urine, were laid upon a block and beaten with staves or battledors. It was with one of these, according to a fragment of Hegesippus preserved by Eusebius, that the Jews beat the Apostle James the younger until he died. When the clothes had been trodden and beaten, they were hung up for the water to drain from them. They then scoured them with fullers' earth and a portion of nitre : after this they fumigated them with sulphur ; then they carded them with a sort of thistle, and last of all they applied chalk in some way or other to brighten the colour, as Pliny says xxxv. 17: *Veros autem et pretiosos colores emollit cimolia, et quodam colore exhilarat contristatos sulphure*.—Schoettgenio *On the ancient Methods of Fulling*. See also *The present State of the Republic of Letters*, vol. i. page 150.

48. *Green vegetable matter*.—Page 436, line 16.

“The transition,” says Sprengel, “of one organical kingdom of nature into the other, and the impossibility of separating the two by an exact line of demarcation, becomes obvious to those who, with Needham, Priestley, and Ingenhousz, have observed the metamorphosis of the animalcula infusoria into real conservæ. To make this experiment, no particular infusions are required ; a vessel filled with pump-water, and exposed to the sun, without being agitated, is sufficient for the purpose. First of all, a delicate green covering is seen to be formed on the surface of the water, consisting of numberless and infinitely minute molecules, that manifest animal motion ; these, after some time, disappear, and are transformed into vegetable filaments, which, like all green surfaces of plants, yield oxygen gas when exposed to the influence of the sun.”—Sprengel's *Introduction to the Study of Cryptogamous Plants*, octavo, London 1810.

49. *Lead an insidious poison*.—Page 445, line 30.

In the province of Poitou there was formerly a disease called the colic of Poitou : but this is no longer common either in France or Germany, since the laws of these countries have made the adulteration of wine with lead, punishable by death. A similar disease was prevalent in the counties of Hereford, Gloucester and Worcester, when leaden utensils were employed in making cider. Dr. Baker, who was physician to Her late Majesty, the Queen of George III., relates that this disease was likewise prevalent in the cider districts of Devonshire, and that on inquiry he found the stones which compose the circular trough in which the apples are ground, to be cramped together by iron, with melted lead poured into the interstices ; and also that many cider presses were to be seen which were lined entirely with lead. Dr. Saunders actually procured $4\frac{1}{2}$ grains of lead from 18 quarts of Devonshire bottled cider.—See *An Essay on the Endemial Colic of Devonshire*, by George Baker, M.D.

London 1767. Dr. Franklin has stated, that leaden-worms were formerly used at Boston in America, for the distillation of rum, and that such disorders were produced in consequence of this practice, that the Government found it expedient to enact a law forbidding the use of any worms for stills except such only as were made of pure tin. Some interesting observations on the danger of employing leaden vessels for holding water, or for culinary purposes, will be found in Dr. Lambe's *Essay on the Properties of Spring Water*, 8vo, 1803.

50. *Processes of decoction, distillation, &c.*—Page 455, line 38.

Steam has long been employed for the purposes of evaporation and distillation in the laboratory belonging to the Apothecaries' Company of London; and very lately its use has been considerably extended, and a more complete apparatus for effecting a great variety of processes of solution, evaporation, and distillation, by the agency of steam, has been erected. This extensive apparatus was constructed by Mr. Mainwaring under the direction of W. T. Brande, Esq., who has furnished me with the following description of the whole:

The steam laboratory is a brick building lighted from above, about 50 feet long, lofty and well ventilated by apertures in the roof. The steam is supplied from two boilers placed in buildings separate from the laboratory; the largest of which is of the common waggon shape, made of copper, and calculated for the supply of a six-horse steam engine. It is furnished with a float-stone, which acts by means of a lever upon an index placed in the laboratory for the purpose of showing the level of the water; with a mercurial gauge indicating the pressure of the steam, which is usually worked at between 7 and 8 inches; and with a safety valve which opens whenever the pressure exceeds that which is capable of supporting 12 inches of mercury in the syphon. A forcing-pump is also annexed to the boiler, by which it is occasionally supplied with hot water resulting from the condensation of the steam in the various vessels.

The main steam pipe, which is 6 inches in diameter, is conducted round the laboratory in a cavity of brickwork covered by moveable cast-iron plates, and is accompanied by a smaller pipe, which receives and conveys the water resulting from the condensation of the steam into a cistern properly supplied with valves, whence it is occasionally pumped back into the boiler. A small steam pipe with a register-cock passes to each of the stills and evaporators, each of which also sends off a condensed liquor-pipe into the main for its reception.

The boilers and evaporators are twelve in number: 4 are of pewter, 1 of iron, and 7 of copper. Four of these are capable of holding from 150 to 300 gallons; four contain about 100 gallons; and four from 10 to 20 gallons: there are also some smaller vessels of the same kind, generally used as water baths.

The stills are seven in number: of these the largest contains 500 gallons, and has a distinct worm-tub; two contain 200 gallons each, and one contains 150 gallons; these are of copper. There is also a pewter still of about 30 gallons, and one of lead for the distillation of ether.

These five stills have two condensing tubs. Lastly, there is a still which with its head and worm are entirely of stone-ware; it is chiefly employed for distilling spirit of nitric ether.

With the exception of the leaden ether-still, all the above vessels are heated by the circulation of steam upon their exterior, being coated with cast-iron jackets, and having a space between the two of about half an inch diameter, into which the steam passes from the main by the register cocks, and from which the condensing pipes pass off. A blow-cock is attached to each vessel, to allow of the escape of the air when the steam is first turned on.

The other boiler above adverted to is calculated for the production of high-pressure steam, with a pressure of 100 lbs. on the square inch; it is applied in another part of the building to various purposes of evaporation, solution, decoction, &c., and in addition only supplies the ether still in the steam laboratory, which is heated by a coil of leaden pipe, by which the temperature requisite for the production of ether from alcohol and sulphuric acid is obtained. The waste steam of these boilers is condensed into a large cistern of water in another part of the building.

Independent of the saving of fuel in consequence of the employment of steam as above described, there result from it other more important advantages, such as safety from fire in the distillation of spirituous and ethereal preparations; prevention of burning or of empyreuma in the evaporation of extracts; and exclusion of the dust and smoke which fires under the separate vessels would necessarily occasion.

Besides the distillatory and evaporatory apparatus, there are also two large drying stoves heated by steam, and several wooden and other vessels for saline solutions, &c. which are occasionally adapted to the steam apparatus, and heated by an immense coil of leaden pipe.

This lengthened description of the apparatus at Apothecaries' Hall has been given for the purpose of showing the great economy of using steam in all the common operations of a chemical laboratory. Another expedient for evaporating heavy or viscous fluids with safety and economy has also been lately introduced, which consists in making oil at a high temperature the medium by which the heat is conveyed.

In the refining of sugar, great inconvenience had arisen from the circumstance of the sugar being usually boiled by a naked fire, which generally burns a part of the sugar, and occasions a portion of the remainder to be converted into molasses, which is more a product of the fire than a natural educt from the raw sugar. In consequence of this, Mr. Daniel Wilson invented a mode of boiling sugar in coppers without fire-places, merely by forcing heated whale-oil through a coil of metallic pipes lying in the midst of the syrup within the boiler.

For a full account of this important apparatus, which in my opinion might be employed with great advantage in many processes besides that of refining sugar, the reader is referred to an octavo volume entitled *A Report of the Trial of the Action brought by Messrs. Severn, King and Co. against the Imperial Insurance Company, before Lord Chief Justice Dallas and a Special Jury, &c.* and to some papers of mine in the 20th, 21st, and 23rd Numbers of the *Journal of Science, Literature and the Arts*, edited at the Royal Institution of Great Britain

NOTES TO ESSAY XIV.

ON SAL-AMMONIAC.

51. *Known to the ancients.*—Page 457, line 2.

It was not until after the Essay on Sal-ammoniac was printed, that I became acquainted with Professor Beckmann's opinion respecting the pretended antiquity of this salt. My readers must however now be informed, that this learned man has asserted that the sal-ammoniac of the ancients was nothing more than impure marine salt. He acknowledges the name is old; but, says he, "as those who, in consequence of the name, considered the *alumen* of the ancients to be our alum, and their *nitrum* to be our salt-petre, were in an error, we should be equally so were we to consider their sal-ammoniac to be the same as ours." Dioscorides and Pliny speak of sal-ammoniac in some places as though it were common salt; but Pliny says also that it was found in the dry sandy deserts of Africa, as far as the oracle of Ammon; and on the other side of the question, Columella, in a prescription for the eye, recommends *rock-salt*, either Spanish, *Ammoniacal*, or Cappadocian.—See Beckmann's *History of Inventions and Discoveries*, London, 1814, vol. iv. p. 360. Sal-ammoniac was however most certainly known in the 15th century, as Agricola describes it as a salt entirely dissipated in the fire, and as employed in the production of a celestial blue colour; and Biringoccio, who wrote in 1540, recommends nitric acid prepared with sal-ammoniac for dissolving gold.

52. *Uses of ammonia.*—Page 461, line 22.

In addition to the list of uses of ammonia which I have enumerated, I wish to notice that a modern traveller has related the case of an Indian who was bitten by a rattlesnake, and perfectly cured in a few days by the external and internal use of volatile alkali alone, although the poor creature lay at the point of death, and betrayed the most dreadful symptoms.—*Travels in South America* by Don Felix di Azara, 4 volumes octavo, Paris 1809.

NOTES TO ESSAY XV.

ON EDGE TOOLS.

53. *Instruments of stone.*—Page 471, line 20.

In the 1st volume of the *Transactions of the American Antiquarian Society*, an antique axe-head is described, made of a species of green stone equal to Ægyptian granite and polished in the neatest manner. In the same work mention is made of a fish-spear, with six or seven long prongs, perfectly separated and barbed, carved out of calcedony. It is difficult to conceive how such instruments could have been made even by means of steel instruments. Page 230.

54. *Imperial foundries.*—Page 475, line 37.

What has been said of the foundries which were established in this country by the Romans for making iron might be confirmed, if there were any doubt of the fact, by a circumstance which occurred about forty years ago in Wales, near the town of Brecknock. In October 1783, as some labourers were felling a tree, the roots of which tore up the earth, some small pillars were presented to view. It afterwards appeared that these belonged to a Roman work consisting of three baths; one hot, the two others cold. The state of this curious relic is described by Mr. Hay, who has also given a good engraving of it. In one of the passages to the baths was found a bar of *malleable iron*, four feet long. See *Archæologia*, vol. vii. At this period few persons in Europe were acquainted with a method of making cutting-instruments either of iron or steel; for it is related that the inhabitants of the northern countries of Europe believed that swords were made by certain pygmies who were concealed in the mountains.—Bergman's *Physical Essays*, vol. iii. p. 89.

55. *First made in London.*—Page 476, line 41.

As many centuries have elapsed since our ancestors learnt the art of making armour and offensive weapons of steel, it seems extraordinary that so long a period should have intervened before they acquired the method of making the most useful implements of common life in that metal. It has already been shown that table-knives were not fabricated in London until the year 1563; and it is related by Stowe, that needles were not sold in Cheapside until the reign of Queen Mary, and then they were made by a Spanish Negro, who refused to discover the secret of his art.

Even the pin was not known in England till towards the middle, or latter end, of the reign of Henry VIII. the ladies until then using ribbons, loops, skewers made of wood, of brass, silver, or gold.

56. *Damascus swords.*—Page 495, line 40.

The sabres of Damascus have given rise to a curious art in the working of iron and steel called *Damaskeening*, which consists in making incisions therein and filling those up with gold or silver wire. This process is employed chiefly in enriching sword blades, and the locks of pistols. Dr. Rees in the *Cyclopædia*, vol. xi. has described the method by which this artificial damasking is effected, and which I think worth transcribing.

“The name which this art bears shows the place of its origin, or at least the place where it has been practised in the greatest perfection, viz. the city of Damascus in Syria; though M. Felibien attributes the perfection of the art to his countryman Cursinet, who wrought under the reign of King Henry IV.

“Damaskeening is partly mosaic work, partly engraving, and partly carving: as mosaic work, it consists of pieces inlaid; as engraving, the metal is indented or cut in creux; and as carving, gold and silver are wrought therein *in relief*.

“There are two ways of damaskeening; in the first, which is the most beautiful, the artists cut into the metal with a graver and other tools proper for engraving on steel, and afterwards fill up the incisions or notches with a pretty thick silver or gold wire. In the other, which is only superficial, they content themselves to make hatches, or strokes across the iron, &c. with a cutting knife, such as is used in making small files. As to the first, it is necessary the gravings or incisions be made in the dove-tail form, that the gold or silver wire, which is thrust forcibly into them, may adhere the more strongly. As to the second, which is the more usual, the method is this: Having heated the steel till it changes to a violet or blue colour, they hatch it over and across with the knife, then draw the ensign or ornament, intended, on this hatching, with a fine brass point or bodkin. This done, they take fine gold wire, and conducting or chasing it according to the figures already designed, they sink it carefully into the hatches of the metal with a copper tool.” Some of this work is very durable and extremely beautiful. See p. 495—497 and p. 505 of this volume.

NOTES TO ESSAY XVII.

ON CALICO-PRINTING.

57. Alum.—Page 527, line 27.

Professor Beckmann, in a memoir published in the *Gottingen Philosophical Transactions for the year 1778*, and also in his *History of Inventions and Discoveries*, has asserted that alum was entirely unknown to the Greeks and Romans; and that the triple salt, the true sulphate of alumina and potash, was first discovered in the East so late as the 12th century.

Herodotus mentions Egyptian alum, and says when the people of Delphos were collecting a contribution to rebuild their temple, the King of Egypt sent them a thousand talents of alum.—*Herodotus*, lib. ii. cap. 180. Diodorus Siculus and Pliny say that the island of Melos was celebrated in their time on account of its alum. But Mr. Beckmann asserts that the article which these writers refer to was *martial vitriol*, and not alum, and that it was celebrated in medicine, and used for dyeing black. He proceeds to remark, that the invention of the true alum must have been later than the 12th century; that in the 15th century there were alum-works in the neighbourhood of Constantinople, and that in the middle of that century the discovery was brought into Europe.

One of the earliest works in Europe for the manufacture of alum was at Tolfa in the Italian States, founded by the son of a celebrated lawyer who traded to Constantinople in Italian cloths, and took that opportunity of making himself acquainted with the method of boiling alum. In England the first alum-work was erected at Gisborough in Yorkshire, in the reign of Queen Elizabeth, by Sir Thomas Chaloner, an ancestor of the present representative in parliament for the city of York, who, notwithstanding the anathemas of the Pope, was warmly patronised in his own county by Lord Sheffield and other neighbouring landholders.

Notwithstanding this positive assertion of Professor Beckmann, I think alum must have been known much earlier, from many considerations, especially from the perfection to which the art of dyeing had attained in several parts of the East, and in some countries of Europe; and also from some Asiatic proverbs and superstitions which are connected with this salt. It was an opinion of Mr. Harmer, that the practices and customs of the East are the same now as they were several centuries ago; and the superstitions of a people are generally of great antiquity. Dr. Russell gives the following relation: "Of all the species of superstition, that of the Arabian belief of the influence of *evil eyes* is," says he, "the most extraordinary. Children are supposed to be more liable to this malignant fascination than others, and they are provided with various charms for their defence; but the most depended upon is a piece of *alum* fastened upon the head-dress of the child. The alum, as they assert, intercepting the baleful influence of the eye, is split by it into pieces, and the child remains unhurt." Dr. Russell relates, that while he was at Aleppo he heard it asserted, and it was generally believed, that a Kurdeen lately deceased had been known to crack a large crystal vase, by merely looking at it with steadfastness from a distance.—Dr. Russell's *Natural History of Aleppo*, in two volumes, 4to, London 1794.

58. *The Phœnicians*.—Page 527, line 35.

That the Phœnicians made great profit by their trade to Britain for tin, is evident from a story which is told by Strabo, who says that "in the most ancient times the Phœnicians from Cadiz were the only persons who traded to these islands, concealing that navigation from all others." When the Romans once followed a Phœnician ship with a design to discover this market, the master wilfully ran his ship amongst shallows, and the Romans following him were involved in the same danger. The Phœnician, by throwing part of his cargo overboard, made his escape; and his countrymen were so well pleased with his conduct, that they ordered all the loss he had sustained to be paid out of the public treasury."—*Strabo*, lib. iii. By these prudent precautions the Phœnicians enjoyed a profitable and exclusive trade to these islands for about three hundred years. The people of Cornwall and of the Scilly Islands understood the arts of refining and working this valuable metal several centuries before the first Roman invasion. Diodorus Siculus says that "those Britons who lived near the promontory Belcrium, (the Land's End) by means of their conversation with merchants which come thither for tin, are more civil than the rest to strangers. They dig their tin out of a stony ground; and when they have dilated it by the fire, they carry it to a certain British island called *Icta*, near which there are places which appear to be islands when it is full sea, but at low water, the shore being then dry, they carry over their tin in carts. Out of these islands the merchants transport their tin into Gallia, and from thence they convey it by horses to the head of the river Eridanus."—Cogan's *Diodorus Siculus*, London 1653, p. 236. The tin mines of Cornwall have been worked ever since this period. Even so long ago as the year 1198, Henry de Casteilun, Chamberlain of London, charges himself with 379*l.* 18*s.* (a large sum in those days)

which he had received in fines from the merchants of London for leave to export tin.—Madox's *History and Antiquities of the Exchequer*, folio, London 1711, p. 531. Dr. Campbell says that the mines of Cornwall produce annually two hundred thousand pounds worth of tin, which is four times as much as they did in the last century.—Campbell's *Political Survey of Great Britain*, vol. i. p. 40. The quantity of tin raised is so much more than the consumption of Europe requires, that the miners of late years have allowed the East India Company to take sometimes one-half and at other times two-thirds of the whole quantity raised, at the low price of 70s. per cwt., which is not more than two-thirds of the usual price; a circumstance which very much enhances the price of tin to the British manufacturers. The Prince of Wales receives a royalty of 4s. 4d. per cwt. from about 3500 to 4000 blocks quarterly, each block weighing on an average three hundred weight and a quarter; besides which, he has the perquisite of a piece cut off the corner of each block, when it goes to Truro or Penzance, to receive the royal stamp.

59. *Laid on with a brush.*—Page 529, line 34.

As all the colours on Indian calicoes are imparted by the pencil, it appears to me that whenever the trade to the East is completely open, a fine opportunity will be afforded of selling immense quantities of British printed goods; for though this is an article of manufacture which the East India Company has not yet been able to introduce, on account of the attachment of the natives to their own peculiar style of work, yet the case might be otherwise, if the country were regularly supplied with British goods, printed in a style suitable to that market, and in colours equally permanent with those of their own production. The difference there would be in price is almost incalculable; for patterns which would require several weeks to complete in India, might, by means of the copper-plate-press and the cylinder, be done here in a few hours.

60. *Weaving calicoes.*—Page 533, line 3.

Weaving calicoes by steam was adopted nearly twenty years ago by Messrs. Horrocks and Co. of Stockport in Cheshire, and by other individuals at Glasgow; but since then Messrs. Lightholder and Anderton at Chorley in Lancashire have had a large establishment for weaving calicoes by steam on a new principle. Being desirous of seeing this manufactory, in the year 1813 I obtained permission of one of the proprietors to view it, who attended me himself, and with the utmost politeness explained to me the nature and use of every part of the machinery. The first room I entered was full of machines for dressing the warp. This is done by hard brushes about four feet long, attached at each end to a strap that is carried round a small wheel, so that the brush revolves with it, and at every revolution brushes the warp, which is properly extended, and passes during the operation slowly from one roller, and is wound by the machinery upon another situated at some distance from it. At every revolution of the brush, the warp dips into a long narrow trough of thick flour paste, which is designed to keep the whole moist and make the brushes

work well : the whole of these motions are given to the machinery by steam. In the upper rooms there are 60 looms, which are constantly in motion. The shuttles move with great rapidity, and one woman is found to be sufficient to attend three looms.

61. *British gum*.—Page 535, line 26.

Having only slightly adverted to this substance in the Essay on Calico-printing, it may be expected that its manufacture should in some measure be explained :—For producing the article, all that is necessary is, to expose dry starch in shallow iron pans to the heat of an oven for an hour or more, until it assumes a peculiar colour well known to those who are in the habit of conducting the process. It is then removed from the furnace, and ground to a very fine powder, for sale.

When the starch has acquired the heat of about 600°, it swells considerably, becomes soft, and exhales a very powerful smell. At this time it becomes yellow, and afterwards of a cinnamon brown ; when it is drawn from the oven, and allowed to cool.

It is observable that starch by this treatment loses all its amylaceous properties, and acquires the properties of gum. It is soluble in cold water, which is not the case with starch ; and, unlike starch, it will not produce a blue compound when its solution is mixed with a dilute solution of iodine. For the other properties of this substance see a memoir by Mons. Dœbereiner, Professor of Chemistry at Jena, in the *Annales de Chimie*, tom. xc. p. 29—42.

In the years 1817 and 1818, Messrs. Turner, Woodheads & Co. of Rotherham had a tedious dispute with the Board of Excise, in consequence of some officers from that Board having made several seizures of large quantities of British gum which had been prepared in their starch-manufactory, and were seized under the pretence of its being *brown* starch that had not paid duty. There being an act of parliament to restrain the makers of starch from having at one time more than 28lbs of *loose* starch in their possession, under the penalty of 100*l.* on each seizure, and 10*s.* for every pound of starch so found, three distinct seizures of British gum belonging to Messrs. Turner & Co. were made, with a view to the recovery of these penalties, which amounted to more than 3000*l.*

In this exigency I was applied to, and samples of the article seized were sent to me for analysis. These were examined with great care ; and when I found that they did not possess the properties of starch, and was assured that it could be proved on oath that the starch from which the British gum had been made had paid the usual duty, I advised the manufacturers to resist the payment of the penalties. Accordingly in the month of February 1818 the cause came on to be tried in the Court of Exchequer, in which I was subpœnaed as an evidence for the defendants ; and having obtained permission to repeat in Court the experiments by which I had ascertained the points in which British gum differs from starch, the proofs were considered to be so decisive, especially the one by the solution of iodine, that a verdict was immediately pronounced for the defendants.

A TABLE

OF

THE EQUIVALENT NUMBERS

OF

VARIOUS SUBSTANCES,

MOST OF WHICH ARE MENTIONED IN THESE ESSAYS.

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>
Acid, acetic, hyd. 2, carb. 24, oxy. 24	50
arsenic, arsen. 38, oxy. 24	62
arsenious, arsen. 38, oxy. 16	54
benzoic, hyd. 6, carb. 90, oxy. 24	120
boracic, boron 8, oxy. 16	24
carbonic, carb. 6, oxy. 16	22
chloric, chlor. 36, oxy. 40	76
chloriodic, iod. 125, chl. 36	161
chlorocarbonic, chlor. 36, carb. ox. 14	50
chlorocyanic, chlor. 36, cyan. 26	62
chromic, chr. 28, oxy. 24	52
citric (dry), carb. 24, oxy. 32, hyd. 2	58
cryst. cit. ac. 58, water 18	76
columbic, col. 144, oxy. 8	152
fluoboric, fluor. 16, boron 6	22
fluoric, fluor. 16, hyd. 1	17
gallic, carb. 36, oxy. 24, hyd. 3	63
hydriodic, iod. 125, hyd. 1	126
hydrocyanic, carb. 12, nit. 14, hyd. 1	27
hydrophosphorous, phos. ac. 40, water 9	49
hyposulphuric, sulph. 16, oxy. 20	36
hyposulphurous, sulph. 16, oxy. 8	24
iodic, iod. 125, oxy. 40	165
lactic	46
malic	70
molybdic, moly. 48, oxy. 24	72
molybdous, moly. 48, oxy. 16	64
muriatic, chlor. 36, hyd. 1	37
nitric, dry, nit. 14, oxy. 40	54
liquid, (sp. gr. 1.50) nit. ac. 54, water 18	72
nitrous, nit. 14, oxy. 32	46
oxalic, carb. 12, oxy. 24	36
cryst. 4 waters, oxal. ac. 36, water 36	72

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>
Acid, oxychloric, chlo. 36, oxy. 56	92
oxyodic, iod. 125, oxy. 40	165
phosphoric, phos. 12, oxy. 16	28
phosphorous, phos. 12, oxy. 8	20
saccholactic, hyd. 4, carb. 36, oxy. 64	104
selenic, sel. 40, oxy. 16	56
succinic, carb. 24, oxy. 24, hyd. 2	50
sulphuric, (dry,) sulph. 16, oxy. 24	40
liquid, (sp. gr. 1.85) sulph. ac. 40, water 9	49
sulphurous, sulph. 16, oxy. 16	32
tartaric, carb. 24, oxy. 40, hyd. 2	66
tungstic, tung. 96, oxy. 24	120
uric, carb. 36, nit. 28, oxy. 8	72
Alum, (dry) sulph. alumi. 132, bi-sulph. pot. 128	260
cryst. (25 waters,) alum. dry 260, water 225	485
Alumina, alum. 18, oxy. 8	26
acetate, alum. 26, ac. acid 50	76
sulphate, ox. alum. 26, sulph. ac. 40	66
Alumium	18
Ammonia, nitrog. 14, hyd. 3	17
acetate, amm. 17, acet. ac. 50	67
arsenate, amm. 17, ars. ac. 62	79
benzoate, amm. 17, ben. ac. 120	137
carbonate, amm. 17, carb. ac. 22	39
bicarbonate, amm. 17, carb. ac. 44	61
chlorate, amm. 17, chlor. ac. 76	93

AN ALPHABETICAL TABLE OF CHEMICAL EQUIVALENTS. 603

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>
Ammonia, chromate, amm. 17, chr. ac. 52	69
citrate, amm. 17, cit. ac. 58	75
molybdate, amm. 17, mol. ac. 72	89
muriate, amm. 17, mur. ac. 37	54
nitrate, amm. 17, nit. ac. 54	71
oxalate, amm. 17, oxa. ac. 36	53
phosphate, amm. 17, phos. ac. 28	45
phosphite, amm. 17, phos. ac. 20	37
succinate, amm. 17, suc. ac. 50	67
sulphate, amm. 17, sulph. ac. 40	57
sulphite, amm. 17, sulph. ac. 32	49
tartrate, amm. 17, tart. ac. 67	84
Antimony.....	45
chloride, ant. 45, chl. 36	81
iodide, ant. 45, iod. 125 ..	170
oxide 1st, ant. 45, oxy. 8	53
2nd, ant. 45, oxy. 16	61
sulphate, ox. ant. 53, sulph. ac. 40	93
sulphuret, ant. 45, sulph. 16	61
oxalate, ox. ant. 53, oxal. ac. 36	89
phosphate, ox. ant. 53, phos. ac. 28	81
phosphuret, ant. 45, phos. 12	57
tartrate, ox. ant. 53, tart. ac. 67	120
Arsenic.....	38
acid, ars. 38, oxy. 24	62
chloride, ars. 38, chl. 72 ..	110
muriate, ox. ars. 54, mur. ac. 74	128
white oxide, ars. 38, oxy. 16	54
sulphuret, ars. 38, sulph. 16	54
Azote.....	14
Barium.....	70
chloride, bar. 70, chlor. 36	106
iodide, bar. 70, iod. 125 ..	195
oxide, bar. 70, oxy. 8	78
peroxide, bar. 70, oxy. 16	86
phosphuret, bar. 70, phos. 12	82
sulphuret, bar. 70, sulph. 16	86
Barytes, bar. 70, oxy. 8	78
acetate, bar. 78, acet. ac. 50	128
arseniate, bar. 78, ars. ac. 62	140
arsenite, bar. 78, ars. ac. 54	132
benzoate, bar. 78, benz. ac. 120	198

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>
Barytes, borate, bar. 78, bor. ac. 24 ..	102
carbonate, bar. 78, carb. ac. 32	100
chlorate, bar. 78, chl. 76 ..	154
chromate, bar. 78, chr. ac. 52	130
citrate, bar. 78, cit. ac. 58	136
fluuate, bar. 78, fluor. ac. 17	95
gallate, bar. 78, gal. ac. 63	141
hydrate, bar. 78, water 9	87
hydriodate, bar. 78, hyd. 126	204
iodate, bar. 78, iod. ac. 165	243
malate, bar. 78, mal. ac. 70	148
molybdate, bar. 78, mol. ac. 72	150
muriate, bar. 78, mur. ac. 37	115
nitrate, bar. 78, nit. ac. 54	132
cryst. nit. bar. 132, water 18	150
oxalate, bar. 78, ox. ac. 36	114
phosphate, bar. 78, phos. ac. 28	106
phosphite, bar. 78, phos. ac. 20	98
seleniate, bar. 78, sel. ac. 56	134
succinate, bar. 78, suc. ac. 50	128
sulphate, bar. 78, sulph. ac. 40	118
sulphite, bar. 78, sulph. ac. 32	110
tartrate, bar. 78, tart. ac. 67	145
tungstate, bar. 78, tung. ac. 120	198
urate, bar. 78, ur. ac. 72	150
Bismuth.....	71
acetate, ox. bis. 79, acet. ac. 50	129
arseniate, ox. bis. 79, ar. ac. 62	141
chloride, bis. 71, chl. 36 ..	107
citrate, ox. bis. 79, cit. ac. 58	137
iodide, bis. 71, iod. 125 ..	196
nitrate, ox. bis. 79, nit. ac. 54	133
oxalate, ox. bis. 79, oxa. ac. 36	115
oxide, bis. 71, oxy. 8	79
sulphate, ox. bis. 79, sulph. ac. 40	119
sulphuret, bis. 71, sulph. 16	87
tartrate, ox. bis. 79, tart. ac. 67	146
Borax, soda 32, bor. ac. 48	80
Boron.....	6
Calcium.....	20
chloride, cal. 20, chl. 36 ..	56
fluoride, calc. 20, fluor. 16	36
iodide, calc. 20, iod. 125 ..	145
oxide, (lime) calc. 20, oxy. 8	28
phosphuret, calc. 20 phos. 12	32
sulphuret, calc. 20, sulph. 16	36
Calomel, merc. 200, chlor. 36	230

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>	<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>
Carbon	6	Copper, oxide, copp. 64, oxy. 8. . .	72
hydrochloride, chlo. 36, olef.		2nd, copp. 64, oxy.	
gas 14	50	16	80
perchloride, carb. 12, chlo.		perarsenate, ox. copp. 80.	
108	120	ars. ac. 124.	204
protochloride, carb. 6, chlor.		protarsenate of, ox. copp.	
36	42	72, ars. ac. 62	134
oxide, carb. 6, oxy. 8.	14	sulphate, ox. copp. 80, sulph.	
phosphuret, carb. 6, phos. 12.	18	ac. 80	160
sulphuret, carb. 6, sulph.		crystallized, sulph.	
32	38	copp. 160, water 90	250
Carburet of nitrogen, carb. 12, nit.		sulphite, ox. copp. 80, sulph.	
14	26	ac. 32	112
Carburetted hydrogen, carb. 6, hyd.		succinate, ox. copp. 72, suc.	
1	7	ac. 50	122
Chloride of nitrogen, nit. 14, chl.		tartrate, ox. copp. 80, tart.	
144.	158	ac. 132	212
Chlorine	36	Corrosive sublimate, merc.	
Chloric ether, chlor. 36, olef. gas.		200, chlor. 72.	272
14	50	Cyanogen, carb. 12, nit. 14.	26
acid, chlor. 36, oxy. 40.	76		
Chromium	28	Diamond	6
1st oxide, chrom. 28, oxy.		Fluorine	16
8	36	Glucinum	18
2nd oxide, chrom. 28, oxy.		Glucina, gluc. 18, oxy. 8	26
16	44	Gold	200
3rd oxide, (acid) chrom.		chloride, gold 200, chlor. 36. .	236
28, oxy. 24.	52	iodide, gold 200, iod. 125.	325
Cobalt	30	oxide, 1st, gold 200, oxy. 8. .	208
arsenate, ox. cob. 38, ars. ac.		2nd, gold 200, oxy. 24. .	224
62	100	phosphuret, gold 200, phos. 12.	212
citrate, ox. cob. 38, cit. ac.		sulphuret, gold 200, sulph. 48..	248
58	96	Gum	90
oxalate, ox. cob. 38, oxal.			
ac. 36	74	Hydrogen	1
oxide, cob. 30, oxy. 8.	38	carburetted, carb. 6, hyd. 1. .	7
sulphate, ox. cob. 38, sulph. ac.		phosphuretted, phos. 12, hyd. 1.	13
40	78	sulphuretted, sulph. 16, hyd. 1..	17
tartrate, ox. cob. 38, tart. ac.			
66	104	Iodine	125
Columbium	144	Iron	28
Copper	64	acetate, ox. iron 36, acet. ac. 50.	86
acetate, ox. copp. 80, acet. ac.		carbonate of, ox. iron 36, carb.	
100	180	ac. 22.	58
carbonate, ox. copp. 80,		1st chloride, iron 28, chlor. 36	64
carb. ac. 22.	102	2nd chloride, iron 28, chlor. 54	82
citrate, ox. copp. 80, cit. ac.		chromate, ox. iron 36, chr. ac.	
116	196	52	88
muriate, ox. copp. 80, mur.		citrate, ox. ir. 36, cit. ac. 58. .	94
ac. 74.	154	gallate, ox. ir. 36, gal. ac. 53.	99
nitrate, ox. copp. 80, nit. ac.		muriate, ox. ir. 36, mur. ac. 37.	73
108	188	nitrate, ox. ir. 36, nit. ac. 54.	90
oxalate, ox. copp. 80, oxal.		pernitrate, ox. ir. 40, nit. ac. 81	121
ac. 72	152	oxalate, ox. ir. 36, ox. ac. 36. .	72
and ammonia, oxalate of,		oxide, iron 28, oxy. 8.	36
oxal. copp. 152, oxal. am.		peroxide, iron 28, oxy. 12. . .	40
53	205	phosphate, ox. ir. 36, ph. ac. 28	64
and potash, oxalate of, oxal.		phosphuret, ir. 28, phos. 12. .	40
copp. 152, ox. pot. 84. . .	236	succinate, ox. ir. 36, suc. ac. 50	86
and soda, oxalate of, oxal.			
copp. 152, ox. sod. 68. . .	220		

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>
Iron, sulphate (dry), ox. ir. 36, sulp. ac. 40.....	76
crystallized (7 waters), sulph. ir. 76, wat. 63.....	139
sulphuret, ir. 28, sulph. 16....	44
bisulphuret, ir. 28. sulph. 32.	60
perarsenate, ox. ir. 40, ars. ac. 93.	133
protarsenate, ox. ir. 36, ars. ac. 62.	98
tartrate, ox. ir. 36, tar. ac. 67.	103
Lead.	104
acetate, ox. lead 112, ac. ac. 50	162
arsenate, ox. lead 112, ars. ac. 62.	174
benzoate, ox. lead 112, ben. ac. 120.	232
carbonate, ox. lead 112, carb. ac. 22.	134
chlorate, ox. lead 112, chlor. ac. 76.	188
chloride, lead 104, chlor. 36.	140
chromate, ox. lead 112, chr. ac. 52.	164
citrate, ox. lead 112, cit. ac. 58.	170
gallate, ox. lead 112, gall. ac. 63.	175
molybdate, ox. lead 112, mol. ac. 72.	184
nitrate, ox. lead 112, nit. ac. 54.	166
subnitrate, ox. lead 224, nit. ac. 54.	278
oxalate, ox. lead 112, oxal. ac. 36.	148
oxide, 1st, lead 104, oxy. 8 ..	112
2nd, lead 104, oxy. 12 ..	116
3rd, lead 104, oxy. 16..	120
phosphate, ox. lead 112, ph. ac. 28.	140
phosphite, ox. lead 112, ph. ac. 20.	132
phosphuret, lead 104, phos. 12.	116
uccinate, ox. lead 112, suc. ac. 50.	162
sulphate, ox. lead 112, sulp. ac. 4.	152
sulphite, ox. lead 112, sulp. ac. 32.	144
sulphuret, lead 104, sulph. 16.	120
tartrate, ox. lead 112, tar. ac. 67.	179
and potash, ox. lead 112, tar. ac. 134, pot. 48.....	294
Lime, calcium 20, oxy. 8.	28
acetate, lime 28, ac. ac. 50.	78
arsenate, lime 28, ars. ac. 62.	90

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>
Lime, benzoate, lime 28, ben. ac. 120.	148
borate, lime 28, bor. ac. 24. ..	52
carbonate, lime 28, carb. ac. 22.	50
chlorate, lime 28, chlor. ac. 76.....	104
chromate, lime 28, chr. ac. 52	80
citrate, lime 28, cit. ac. 58.	86
hydrate, lime 28, water 9.	37
iodate, lime 28, iod. ac. 165.	193
malate, lime 28, mal. ac. 70.	98
muriate, lime 28, mur. ac. 37.	65
nitrate, lime 28, nit. ac. 54.	82
oxalate, lime 28, ox. ac. 36.	64
oxyiodate, lime 28, oxy. iod. ac. 165.	193
phosphate, lime 28, phos. ac. 28.....	56
biphosphate, lime 28, phos. ac. 56.....	84
succinate, lime 28, suc. ac. 50.	78
sulphate, lime 28, sulp. ac. 40.	68
crystallized, sulph. lime 68, water 18.	86
sulphite, lime 28, sul. ac. 32.	60
tartrate, lime 28, tart. ac. 67.	95
tungstate, lime 28, tungst. acid 120.	148
Lithia, lith. 10, oxy. 8.....	18
carbonate, lith. 18, carb. ac. 22.	40
chlorate, lith. 18. chlor. ac. 76.....	94
nitrate, lith. 18, nit. ac. 54..	72
phosphate, lith. 18, phosph. ac. 28.	46
sulphate, lith. 18, sulph. ac. 40.	58
Lithium.	10
chloride, lith. 10, chlor. 36.....	46
oxide, lith. 10, oxy. 8	18
iodide, lith. 10, iod. 125....	135
sulphuret, lith. 10, sulph. 16.....	26
Magnesia, mag. 12, oxy. 8.	20
acetate, mag. 20, ac. ac. 50.....	70
arsenate, mag. 20, ars. ac. 62.	82
borate, mag. 20, bor. ac. 24.	44
carbonate, mag. 20, car. ac. 22.	42
bicarbonate, mag. 20, car. ac. 44.....	64
chlorate, mag. 20. chlor. ac. 76.....	96
citrate, mag. 20, cit. ac. 58	78

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>	<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>
Magnesia, hydrate, mag. 20, water		Mercury, arseniate, ox. mer. 208,	
9.	29	ars. ac. 62.	270
hydriodate, mag. 20, hyd.		perarseniate, ox. mer. 216,	
ac. 126.	146	ars. ac. 124.	340
muriate, mag. 20, mur. ac.		borate, ox. mer. 208, bor.	
37.	57	ac. 24.	232
nitrate, mag. 20, nit. ac.		perborate, ox. mer. 216,	
54.	74	bor. ac. 48.	264
oxalate, mag. 20, ox. ac. 36.		carbonate, ox. mer. 208,	
phosphate, mag. 20, ph.		car. ac. 22.	230
ac. 28.	48	bicarbonate, ox. mer. 216,	
succinate, mag. 20, suc.		car. ac. 44.	260
ac. 50.	70	chloride, mer. 200, chl. 36.	236
sulphate, mag. 20, sul. ac.		bichloride, mer. 200, chl.	
40.	60	72.	272
crystallized, sul.		citrate, ox. mer. 208, cit.	
mag. 60, water		ac. 58.	266
63.	123	cyanuret, mer. 200, cyan.	
sulphite, mag. 20, sul. mag.		52.	252
32.	52	hydriodate, ox. mer. 208,	
tartrate, mag. 20, tar. ac.		hyd. ac. 126.	334
67.	87	iodide, mer. 200, iod. 125	325
Magnesium.	12	periodide, mer. 200, iod.	
chloride, mag. 12, chlor.		250.	450
36.	48	nitrate, ox. mer. 208, nit.	
oxide, mag. 12, oxy. 8.	20	ac. 54.	262
Manganese	28	pernitrate, ox. mer. 216,	
acetate, ox. man. 36, ac.		nit. ac. 108.	324
ac. 50.	86	supernitrate, ox. mer. 432,	
arseniate, ox. man. 36,		nit. ac. 54.	486
ars. ac. 62.	98	oxalate, ox. mer. 208, ox.	
carbonate, ox. man. 36,		ac. 36.	244
car. ac. 22.	58	oxide, merc. 200, oxy. 8.	208
chloride, man. 28, chlor.		peroxide, merc. 200, oxy.	
36.	64	16.	216
citrate, ox. man. 36, cit.		phosphate, ox. mer. 208,	
ac. 58.	94	ph. ac. 28.	236
muriate, man. 28, mur.		perphosphate, ox. mer. 216,	
ac. 37.	65	ph. ac. 56.	272
nitrate, ox. man. 36, nit.		sulphate, ox. mer. 208,	
ac. 54.	90	sul. ac. 40.	248
oxalate, ox. man. 36, ox.		persulphate, ox. mer. 216,	
ac. 36.	72	sul. ac. 80.	296
oxide 1st, man. 28, oxy. 8.	36	subsulphate, ox. mer. 216,	
2nd, man. 28, oxy.		sul. ac. 40.	256
12.	40	sulphite, ox. mer. 208, sul.	
3rd, peroxide, man.		ac. 32.	240
28, oxy. 16.	44	sulphuret, mer. 200, sul. 16.	216
phosphate, ox. man. 36,		bisulphuret, mer. 200, sul.	
ph. ac. 28.	64	32.	232
phosphuret, man. 28,		tartrate, ox. mer. 208, tar.	
phos. 12.	40	ac. 67.	275
succinate, ox. man. 36,		tartrate and potash, ox.	
suc. ac. 50.	86	mer. 208, tar. ac. 134,	
sulphate, ox. man. 36,		pot. 48.	390
sul. ac. 40.	76	Molybdenum	
tungstate, ox. man. 36,		1st oxide, mol. 48, oxy. 8.	56
tun. ac. 120.	156	2nd ditto, mol. 48, oxy.	
Mercury.	200	16.	64
acetate, ox. mer. 208, ac.		3rd ditto, mol. 48, oxy.	
ac. 50.	258	24.	72

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>
Molybdenum, sulphuret, mol. 48, sul. 32.	80
Nickel.	30
borate, ox. ni. 38, bor. ac. 24.	62
carbonate, ox. ni. 38, car. ac. 22.	60
chloride, ox. ni. 30, chl. 36. . .	66
citrate, ox. ni. 38, cit. ac. 58.	96
hydrate, ox. ni. 38, water 9. .	47
iodide, ni. 30, iod. 125. . .	155
nitrate, ox. ni. 38, nit. ac. 54	92
oxalate, ox. ni. 38, ox. ac. 36	74
oxide, ni. 30, oxy. 8.	38
phosphate, ox. ni. 38, phos. ac. 28.	66
phosphuret, nic. 30, phos. 12.	42
sulphate, ox. nic. 38, sul. ac. 40.	78
crystallized, sul. nic. 78, water 63. . .	141
sulphuret, nic. 30, sul. 16. .	46
tartrate, ox. nic. 38, tar. ac. 67.	105
Nitric oxide, nit. 14, oxy. 16. . .	30
Nitrogen.	14
chloride of, nit. 14, chl. 144.	158
Nitrous oxide, nit. 14, oxy. 8. . .	22
Olefiant gas, carb. 6, hyd. 1. . . .	7
Oxygen.	8
Phosphuretted hydrogen, pho. 12, hyd. 1.	13
Phosphorus.	12
sulphuret of, pho. 24, sul. 16.	40
Platinum.	96
perchloride, plat. 96, chlor. 72.	168
protochloride, plat. 96, chlor. 36.	132
Potash (dry), pot. 40, oxy. 8. . . .	48
acetate of, pot. 48, ac. ac. 50.	98
ammonio-sulphate, pot. 48, sul. ac. 80, amm. 17. . . .	145
arseniate, pot. 48, ars. ac. 62.	110
binarseniate, pot. 48, ars. ac. 124.	172
arsenite, pot. 48, ars. ac. 54.	102
benzoate, pot. 48, ben. ac. 120.	168
borate, pot. 48, bor. ac. 24.	72
carbonate, pot. 48, carb. ac. 92.	70
bicarbonate, pot. 48, carb. ac. 44.	92
crystallized, dry salt 92, water 9	101

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>
Potash, chlorate, pot. 48, chl. ac. 76	124
chromate, pot. 48, chr. ac. 52.	100
citrate, pot. 48, cit. ac. 58.	106
columbate, pot. 48, col. ac. 152.	200
fluat, pot. 48, flu. ac. 17. . .	65
gallate, pot. 48, gall. ac. 63	111
hydrate, pot. 48, water 9. . .	57
hydriodate, pot. 48, hyd. ac. 125.	173
hydrosulphuret, pot. 48, sul. hyd. 17.	65
iodate, pot. 48, iod. ac. 165.	213
molybdate, pot. 48, mol. ac. 72.	120
nitrate of, pot. 48, nit. ac. 54	102
nitrite, pot. 48, nit. ac. 46	94
oxalate, pot. 48, ox. ac. 36	84
binoxalate, pot. 48, ox. ac. 72.	120
quadoxalate, pot. 48, ox. ac. 144.	192
oxychlorate, pot. 48, ox. chl. ac. 92.	140
phosphate, pot. 48, phos. ac. 28.	76
biphosphate, pot. 48, phos. ac. 56.	104
phosphite, pot. 48, phos. ac. 20.	68
succinate, pot. 48, suc. ac. 50.	98
sulphate, pot. 48, sul. ac. 40.	88
bisulphate, pot. 48, sul. ac. 80.	120
sulphite, pot. 48, sul. ac. 32.	80
tartrate, pot. 48, tar. ac. 67.	115
bitartrate, pot. 48, tar. ac. 134.	182
tungstate, pot. 48, tung. ac. 120.	168
Potassium.	40
chloride, pot. 40, chlo. 36.	76
iodide, pot. 40, iod. 125. . .	165
peroxide, pot. 40, oxy. 24.	64
phosphuret, pot. 40, pho. 12.	52
protoxide, pot. 40, oxy. 8.	48
sulphuret, pot. 40, sul. 16.	56
Selenium.	40
acid, sel. 40, oxy. 16.	56
oxide, sel. 40, oxy. 8.	48
sulphuret, sel. 80, sul. 48. .	128
Silica, sil. 8, oxy. 8.	16
Silicium.	8
Silver.	110
acetate, ox. sil. 118, ac. ac. 50	168
arseniate, ox. sil. 118, ars. ac. 62	180

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>	<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>
Silver, carbonate, ox. sil. 118, car.		Sodium, protoxide, sod. 24, oxy. 8.	32
ac. 22.	140	sulphuret, sod. 24, sulph. 16..	40
chloride, sil. 110, chl. 36.	146	Strontites, stron. 47, oxy. 8.	55
chromate, ox. sil. 118, chr. ac.		acetate, stron. 55, ace. ac.	
52.	170	50.	105
citrate, ox. sil. 118, cit. ac. 58.	176	arseniate, stron. 55, ars.	
cyanuret, sil. 110, cya. 52.	162	ac. 62.	117
molybdate, ox. sil. 118, m. a.		borate, stron. 55, bor. ac.	
72.	190	24.	79
nitrate, ox. sil. 118, ni. ac. 54.	172	carbonate, stron. 55, carb.	
oxalate, ox. sil. 118, ox. ac. 36.	154	ac. 22.	77
oxide, sil. 110, oxy. 8.	118	chlorate, stron. 55, chl.	
phosphate, ox. sil. 118, p. a. 28.	146	ac. 72.	127
phosphuret, sil. 110, phos. 12..	122	citrate, stron. 55, cit. ac. 58.	113
sulphate, ox. sil. 118, s. ac. 40.	158	hydrate, stron. 55, water 9.	64
sulphuret, sil. 110, sul. 16.	126	iodate, stron. 55, iod. ac.	
tartrate, ox. s. 118, tar. ac. 67.	185	165.	220
tartrate, and potash, ox. s. 118,		muriate, stron. 55, mur.	
tar. ac. 134, pot. 48.	300	ac. 37.	92
tungstate, ox. s. 118, tung. ac. 20.	238	nitrate, stron. 55, nit. ac.	
Soda, sod. 24, oxy. 8.	32	54.	109
acetate, sod. 32, ac. ac. 50.	82	oxalate, stron. 55, ox. ac.	
arseniate, sod. 32, ars. ac. 62..	94	36.	91
arsenite, sod. 32, ars. ac. 54.	86	phosphate, stron. 55, phos.	
benzoate, sod. 32, ben. ac. 120.	152	ac. 28.	83
borate, sod. 32, bor. ac. 24.	56	succinate, stron. 55, suc.	
carbonate, sod. 32, car. ac. 22.	54	ac. 50.	105
crystallized, carb. sod. 54, water		sulphate, stron. 55, sulph.	
90.	144	ac. 40.	95
bicarbonate, sod. 32, car. ac. 44.	76	sulphite, stron. 55, sulph.	
chlorate, sod. 32, chl. ac. 76.	108	ac. 32.	87
oxychlorate, sod. 32, oxychl.		tartrate, stron. 55, tar. ac.	
ac. 92.	124	67.	122
chromate, sod. 32, ch. ac. 52..	81	Strontium.	47
citrate, sod. 32, cit. ac. 58.	90	chloride, stron. 47, chl. 36.	83
fluat, sod. 32, flu. ac. 17.	49	iodide, stron. 47, iod. 125.	172
hydrate, sod. 32, water 9.	41	oxide, stron. 47, oxy. 8..	55
iodate, sod. 32, iod. ac. 165.	197	phosphuret, stron. 47,	
molybdate, sod. 32, mol. ac. 72.	104	phos. 12.	59
muriate, sod. 32, mur. ac. 37..	69	sulphuret, stron. 47, sulph.	
nitrate, sod. 32, nit. ac. 54.	86	16.	63
oxalate, sod. 32, ox. ac. 36.	68	Sulphur.	16
phosphate, sod. 32, phos. ac. 28.	60	Sulphuretted hydrogen, sulph. 16,	
biphosphate, sod. 32, phos. ac.		hyd. 1.	17
56.	88	Tannin.	70
phosphite, sod. 32, phos. ac. 20.	52	Tellurium.	38
succinate, sod. 32, suc. ac. 50..	82	chloride, tell. 38, chl. 36.	74
sulphate, sod. 32, sulph. ac. 40..	72	oxide, tell. 38, oxy. 8.	46
crystallized, sulph. sod.		Tin.	59
72, water 90.	162	acetate, ox. tin 67, ace. ac. 50.	117
bisulphate, sod. 32, sulph. ac. 80.	112	arseniate, ox. tin 67, ars. ac. 62.	129
sulphite, sod. 32, sulph. ac. 32..	64	chloride, 1st, tin 59, chl. 36.	95
tartrate, sod. 32, tart. ac. 67..	99	chloride, 2nd, tin 59, chl. 72.	131
and potash, sod. 32, tart.		citrate, ox. tin 67, cit. ac. 58.	125
ac. 134, pot. 48.	214	muriate, ox. tin 67, mur. ac. 37.	104
tungstate, sod. 32, tung. ac. 120.	152	permuriate, ox. tin 67, mur. ac.	
Sodium.	24	74.	149
chloride, sod. 24, chl. 36.	60	nitrate, ox. tin 67, nit. ac. 54..	121
iodide, sod. 24, iod. 125.	149	oxalate, ox. tin. 67, ox. ac. 36.	103
peroxide, sod. 24, oxy. 12.	36	peroxide, tin 59, oxy. 8.	67
phosphuret, sod. 24, phos. 12.	36		

<i>Substances and Composition.</i>	<i>Equiv. Nos.</i>	<i>Substances and Composition.</i>	<i>Equiv Nos</i>
Tin, protoxide, tin 59, oxy. 16....	75	Zinc, carbonate, ox. zinc 43, carb.	
phosphuret, tin 59, phos. 12...	71	ac. 22	65
succinate, ox. tin 67, suc. ac.		chlorate, ox. zinc 43, chl. ac.	
50.....	117	76.....	119
sulphate, ox. tin 67, sulph. ac. 40.	107	chloride, zinc 35, chl. 36.	71
sulphuret, tin 59, sulph. 16	75	citrate, ox. zinc 43, cit. ac. 58.	101
tartrate, ox. tin 67, tart. ac. 67.	134	iodide, zinc 35, iod. 125.....	160
Tungsten	96	nitrate, ox. zinc 43, nit. ac. 54.	97
tungstic acid, tung. 96, oxy.		oxalate, ox. zinc 43, ox. ac. 36.	79
24.....	120	oxide, zinc 35, oxy. 8.	43
Uric acid	45	phosphate, ox. zinc 43, phos:	
Water, oxy, 8, hyd. 1.	9	ac. 28.....	71
Yttrium	32	phosphuret, zinc 35, phos. 12.	47
Yttria, yttr. 32, oxy. 8.	40	succinate, ox. zinc 43, suc. ac.	
Zinc.....	35	50	93
acetate, ox. zinc 43, acet. ac.		sulphate, ox. zinc 43, sulph. ac.	
50.	93	40.....	83
arsenate, ox. zinc 43, ars. ac.		crystallized, sulph. zinc	
62.	105	83, water 63.	146
borate, ox. zinc 43, bor. ac. 24.	67	sulphite, ox. zinc 43, sulph. ac.	
		32.....	75
		sulphuret, zinc 35, sulph. 16. . .	51
		tartrate, ox. zinc 43, tart. ac.	
		67.....	110
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THE END.

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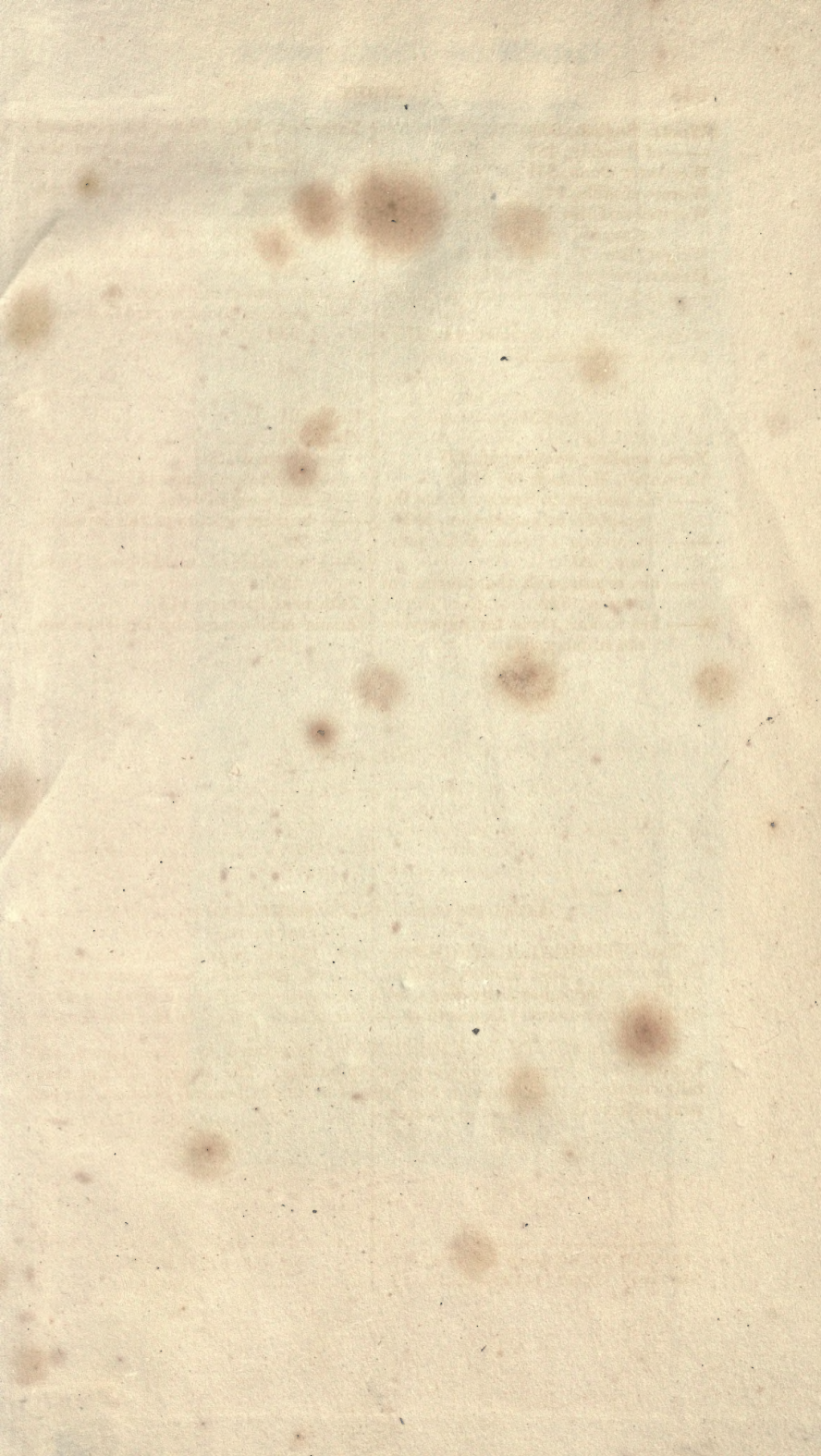
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